The Boucheral earthquake of 8 May 1955

Abstract
This research examines the destructive earthquake that occurred on 8 May 1955 in the northern side of the Dahra massif on the shores of the Mediterranean Sea. The Cheliff Valley has been the site of the two largest earthquakes this century: those of Orléansville 1954 (M_S = 6.70) and El-Asnam 1980 (M_S = 7.45). The Boucheral earthquake occurred eight months after the Orléansville earthquake of 9 September 1954 which claimed 1409 deaths, 5000 injuries and destroyed 33000 constructions and public works. The same epicentral zone has suffered extensive damage during the 1954 Orléansville and 1980 El-Asnam earthquakes. On Sunday, 8 May, 1955, at 21 h 38 min 59 s (GMT), the Tenes-Dupleix coastal zone was struck by a destructive earthquake. The epicentral area, which centred in the small village of Boucheral, is located at about 165 km west of the capital Alger. The main shock, which lasted 8 s, caused only few injuries and making numerous homeless; it destroyed several local traditional houses and colonial farms, and seriously damaged colonial structures. It triggered landslides and rockfalls from the cliff on the road between Tenes and Dupleix. Low-quality constructions contributed substantially to the damage. Intensities have been re-evaluated at several sites and an isoseismal map has been drawn. Maximum intensity reached I_0 = VII (MSK) and covers an area of about 400 square km. Radius of perceptibility was relatively small and the shaking was felt as far as Fort De L'Eau 165 km away with intensity III (MSK). From the intensity data, the macroseismic epicentre has been located near Boucheral, at 36.53°N, 1.46°E. The surface-wave magnitude was computed, without station corrections, at 4.75 (± 0.20).

1. Introduction

The Tenes region was struck by a destructive earthquake on Sunday, 8 May 1955, at 21 h 38 min 59 s (GMT). The same epicentral area have already suffered important damage and loss of life during the Orléansville earthquake of 9 September 1954 which claimed at least 1409 deaths and 5000 injuries and the El-Asnam 10 October 1980 which caused 3000 loss of lives, injuring more than 8500 and making 400000 homeless. The epicentral area, which centred in the village of Boucheral, is located at about 160 km west of the capital Alger. The main shock, which lasted 8 s, caused important damage in the zone containing Tenes, Boucheral, Francis Garnier and their close surroundings. It destroyed several local traditional houses and farms, and seriously damaged colonial constructions. The earthquake has triggered landslides and rockfalls, from the cliff, on the coastal road between Tenes and Dupleix. The shaking was felt, with intensity III$^+$ (MSK), as east as Fort De L'Eau, south as Moliere and west as Inkermann, an area of about 100 km radius.

The main shock was preceded by few slight premonitory shocks and followed by several aftershocks which some of them were strong enough to add damage in the affected region. The earthquake was recorded by many of the seismological stations operating at that time. Using the standard Prague formula, and teleseismic amplitude and period readings from 4 stations, the surface-wave magnitude was calculated, without station corrections, at 4.75 ($\pm$ 0.20).

Careful study of the macroseismic data inferred from a variety of contemporary sources relative to this earthquake has led to a detailed re-assessment of how much damage was caused to humans, man-made structures and to the ground itself. These data have also revealed the type of structures that existed at that time and the state they were in. Combination of the macroseismic data together with the building stock exposed to the shaking have greatly contributed in the re-evaluation of intensities in many sites with an appreciable degree of reliability. Maximum intensity has been re-estimated at I_0 = VII in the MSK intensity scale, has been allocated to Tenes, Boucheral and Francis Garnier, and covers an area of 11 km radius. From the intensity data, an isoseismal map of the earthquake has been constructed and the macroseismic epicentre located, slightly east of Boucheral, at 36.53°N, 1.46°E.

2. Sources of information

A broad investigation for contemporary documents relative to this earthquake was realized in numerous libraries and archive centres. The result of this is mainly a collection of newspaper reports. We found no complete technical report about this event. It was thought that the information about this earthquake would be abundant, particularly in the Algerian and French press, as for past destructive ones. Unfortunately, this was not true; the information either in the press or in the technical reports were rather scarce and confined to colonial villages and farms.

In the press, the most extensive accounts are given in «La Dépêche Quotidienne» and «Le Journal D'Alger» (1955). Benhallou (1985), quoting the archives of the IPGA, summarized in three lines the effects of the earthquake and published an isoseismal map (fig. 1).

In the recent catalogues, the instrumental epicentre of this earthquake was located at: 36.5°N, 1.6°E (ISS, 1955); 36.6°N, 1.5°E (BCIS, USCGS, 1955; Karnik, 1969); 36.436°N, 1.545°E (Mezcua and Martinez, 1983). Maximum intensity was assigned at: VIII (MS), (Rothé, 1957, 1969; Karnik, 1969); VIII (MM), (Benhallou and Roussel, 1971; Khemici in EERI, 1981; Benhallou, 1985) and VII (MSK), (Mezcua and Martinez, 1983). Magnitudes were also calculated at: M = 4.90 (BCIS, 1955); M_S = 4.9 (Karnik, 1969); M_L = 4.80 (PRA); m_b = 4.6 (Mezcua and Martinez, 1983) and m_b = 6.0 (Munuera, 1963).

3. Geographical aspects of the region

The epicentral area lies on the northern flank of the coastal range Dahra which is about 160 km west of the capital Alger. The Dahra contains in its northern part a mountainous zone at which the height is over 1000 m; the Djebel Bissa is culminating at 1157 m, Djebel Sidi Bernous at 1146 m and Djebel Tkelout at 1041 m. This part of the Dahra is characterized by its savage landscape; the cliffs, rectilinear, slip in large longitudinal pieces without the help of earthquakes. If the French settlers were occupying the tiny littoral plains of Tenes, Francis Garnier, Dupleix, Novi and Cherchell where the soil is fertile, water abundant and communications adequate; the native people were gathered in douars sparsely distributed in the small high plateaux or dangerously on abrupt slope of the valleys. The local traditional houses (gourbis) were built with adobe or stone with a thick lime or clay mortar joint and covered with heavy roofs. These douars, composed of a certain number of housing units (gourbis), were densely populated from 40 to 60 inhabitants per square km (Armature Urbaine 1987, 1988).

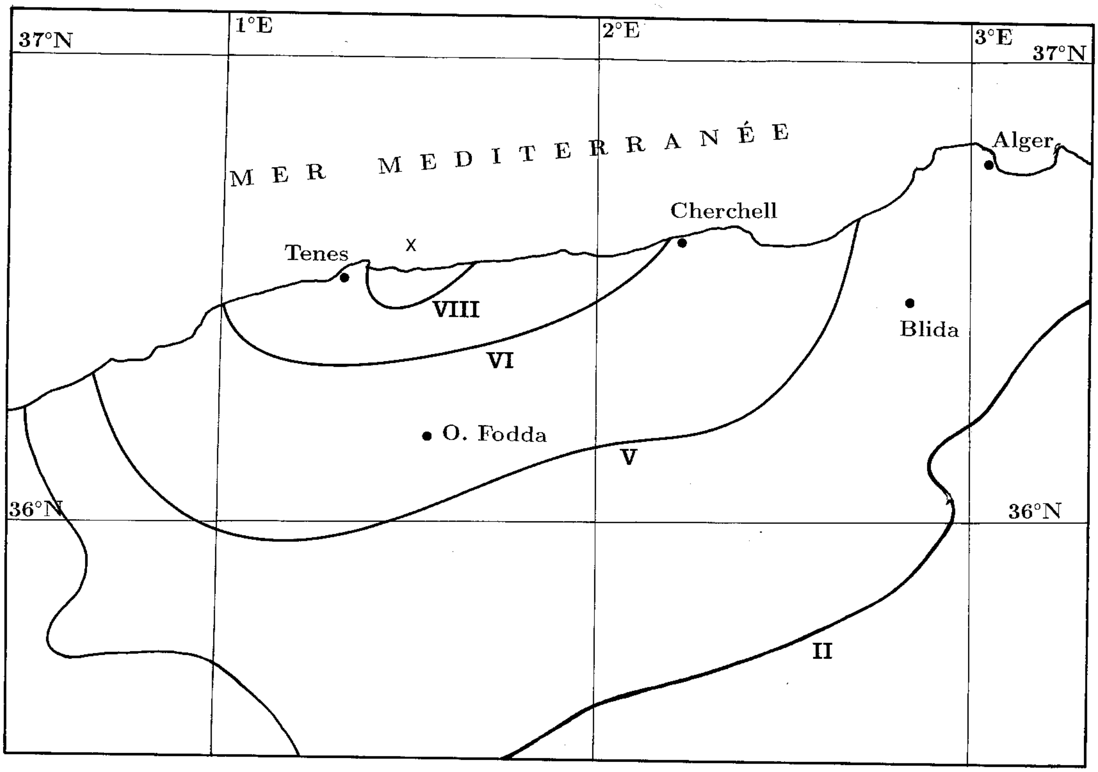

Fig. 1. Isoseismal map (in terms of MM scale) of the main shock of the 8 May 1955 earthquake, after Benhallou (1985). *Redrawn.*

4. Damage and casualty distributions

Collection and careful study of the contemporary accounts relative to this earthquake have substantially contributed in the re-estimation of the amount of damage sustained by man-made structures and by nature, and how the population behaved. It was revealed that, as in past destructive earthquakes, poorly built constructions as adobe, stone and unreinforced masonry structures suffered serious damage from cracks to total collapse. Maximum effects of this shock were experienced within a small zone along the coast between Tenes and Francis Garnier. As a result of the shock, few were injured but no one was killed.

In Boucheral and Francis Garnier the main shock, which lasted 8 s, was strong enough to provoke a general panic among the population which had to flee their homes to the streets. It destroyed several local traditional houses (gourbis) and produced cracks in the relatively well built French settlers' constructions. A farm in the immediate vicinity of the village was entirely destroyed and its inhabitants injured. The school was temporarily closed due to the extent of damage. Livestock around this locality was buried under the rubble of the low-quality stables and killed.

The electricity service was interrupted but no damage to mains was reported. The earthquake triggered landslides and rockfalls, from the cliff, on the coastal road which was obstructed and thus closed to road traffic for two hours. In Tenes the shaking, which lasted 8 s, was strongly felt and caused a considerable emotion among the population. The damage was moderate and consisted of cracks in walls of relatively well built structures already affected during the Orléansville 1954 earthquake. The local traditional houses in the surroundings of Tenes sustained important damage from significant cracks to total destruction. The farm Viquier, located at 20 km of Tenes, suffered important damage; the old building completely collapsed whereas the newly built structures had their walls cracked. In Dupleix the shaking, which lasted 4 s, caused cracks in walls and fall of plaster. It was strong enough to provoke a general panic among the population which fled their homes. No one is reported killed or injured. Further south at about 40 km, in Orléansville which was completely destroyed eight months earlier, during the 9 September 1954 earthquake, the shaking did not cause a general panic but a collective fright among the population. Many people fled their homes, fearing other stronger shocks. Damage consisted of slight cracks in few walls which were already affected during the last earthquake disaster. No other type of damage or victims were reported. At Les Attafs the main shock, which lasted 8 s, caused slight damage but details were not given. In Charon the shaking was strong enough to make the inhabitants flee their homes, fearing of their collapse. No damage or casualty were communicated. In Rouina the earthquake was so strong that people, in the cinema of the village, fled precipitately. Further east, at Duperre, like in other localities in the region, the population fled their habitations to the streets. In the villages of Mentenotte and Cavaignac the damage consisted of few cracks in walls which were affected by the previous Orléansville earthquake. People frightened had fled their homes. In the localities of Kherba, Hammam Righa, Littre, Miliana, Oued Fodda, Ponteba and Malakoff, the shaking caused great concern among their inhabitants. In Cherchell the earthquake was felt during six seconds. No damage or casualty was reported. East of Francis Garnier, at about 145 km, in the capital Alger, the main shock was seriously felt by people in the high rise buildings of Champ de Manoeuvre. Most of the inhabitants living around the 14th floor fled from their apartments to the streets in night clothes. The shock was reported to be felt, but without any details, at Fort De L'Eau, Medea, Lodi, Damiette, Letourneux, Blida, Moliere and Inkermann.

5. Intensity re-evaluation

All the macroseismic data inferred from the sources available to us were used, with reference to the Medvedev-Sponheuer-Karnik – MSK – intensity scale, to re-estimate intensities. After a careful study of these data, maximum intensity I_0 = VII (MSK), has been allocated to Tenes, Boucheral, Francis Garnier and their immediate vicinities, and covers an area of about 11 km radius. This intensity has been attributed to localities where damage consisted of destruction of local traditional houses and cracks in walls of relatively well built European structures. Intensity VI has been confined to Pointe Rouge, Mentenotte, Cavaignac, Flatters, Dupleix and Villebourg. Intensity IV-V has been attributed to Orléansville, Les Attafs, Hanoteau, Chasseriau, Gouraya and Novi. Intensity IV has been assigned to Rouina, Kherba, Duperre, Littre, Oued Fodda, Warnier, Miliana, Ponteba, Malakoff, Charon, Hammam Righa and Cherchell. Intensity III has been allocated to Fort De L'Eau, Alger, Sidi Ferruch, Blida, Lodi, Medea, Damiette, Letourneux, Moliere and Inkermann. Intensities V and VI have been attributed with rigid interpretation of the MSK intensity scale. Intensity III and

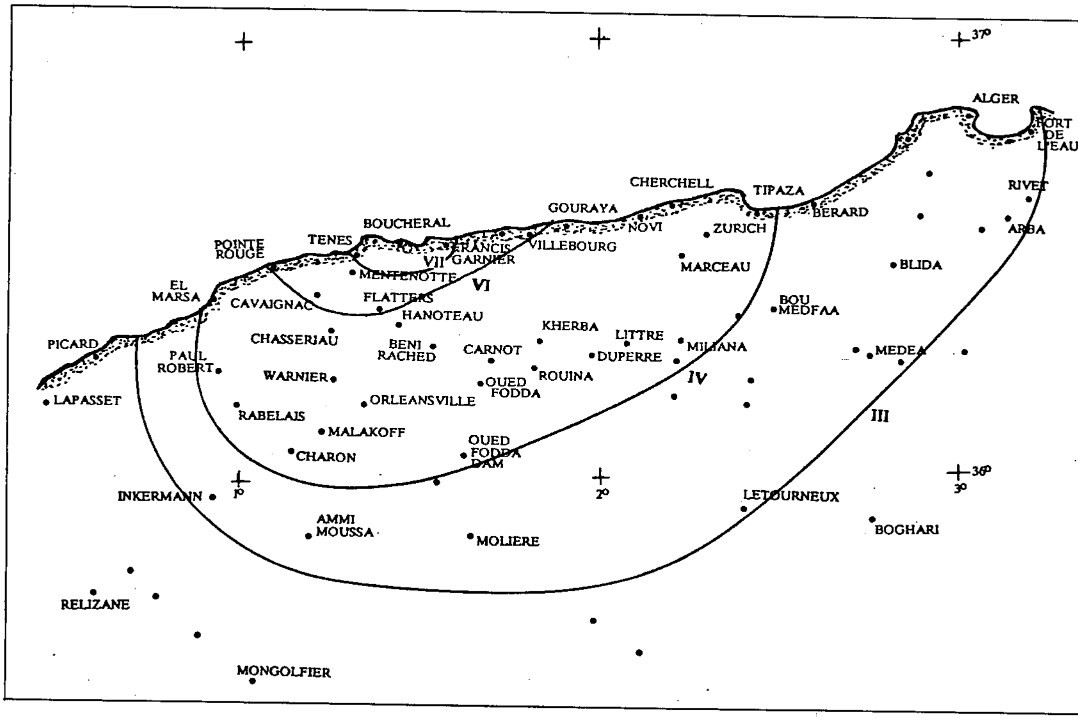

Fig. 2. Isoseismal map (in terms of MSK scale) of the main shock of the 8 May 1955 earthquake. The star shows the macroseismic epicentre of the main shock.

IV have been assigned solely on felt effects and lack of damage to poor-quality structures.

From the intensity data, an isoseismal map of the Boucheral 8 May 1955 earthquake has been constructed and is shown in fig. 2 on which were plotted the re-evaluated intensities.

6. Magnitude determination

The surface-wave magnitude of the main shock has been determined from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 3 seismological stations located at distances between 16° and 34°, and a preliminary epicentre (macroseismic) at 36.53°N, 1.46°E. The data and the results are given in Benouar (1993). The mean period is 12 s and the derived value of M_S, without station corrections, is 4.75 (± 0.20).

7. Foreshocks and aftershocks

The main shock was preceded by slight premonitory shocks on 26 April at 0 h 43 min, on 4 May at 12 h 38 min and 16 h 54 min and also on 5 May at 10 h 40 min and 15 h 3 min. All these foreshocks were recorded at Alger-University station but we found no evidence that they were felt in the affected region. On the other hand, the earthquake was followed by several aftershocks, continuing until early June 1955. The largest aftershocks occurred, with intensity V (MSK), in Francis Garnier on 9 May at 16 h, 17 May at 00 h 45 min, in Duperre on 25 May at 18 h 55 min and in Orléansville on 26 May at 21 h 53 min. The continuity of these significant shocks seriously undermined the spirits of the whole population of the region.

8. Discussion

In terms of the seismic history of Orléansville-Tenes region reported by Hée (1925, 1933), Rothé (1950, 1969), Benhallou and Roussell (1971), Mezcua and Martinez (1983), Benhallou (1985), the Boucheral 8 May 1955 earthquake is by no means an exceptional one. The main destructive shocks known to have struck the region occurred in 1853, 1867, 1876, 1922, 1934, 1954 and 1980 (Orléansville region), in 1872, 1891, and 1905 (Tenes area) and 1891 (Gouraya). The Orléansville-Tenes region seems to be the most seismically active zone in Algeria during the last two centuries.

In order to re-assess the effects of the earthquake and thus re-estimate the intensities with an appreciable degree of reliability, an extensive search for contemporary accounts relative to this event was made. The data retrieved, as the result of the investigation, have showed that, as in past destructive earthquakes in Algeria, constructions built of adobe, stone or unreinforced masonry bearing walls suffered either total destruction or serious damage. As a consequence of the low-quality structures exposed to the shaking, the maximum intensity in any destructive earthquake in the region would appear the same. That is, at intensity IX (MSK) most of the adobe, stone and ordinary masonry constructions are destroyed and any site would look equally, but no more, devastated at higher intensities of the scale. The reconstruction of the macroseismic field of this event is of considerable interest for various reasons. Firstly, it represents one of the destructive earthquakes in Tenes region. Secondly, the same epicentral area, which experienced destructive earthquakes in the past, exhibits today various humans and geographical characteristics met in many other parts of the country. For these main reasons, a detailed study of the effects of this event in this restricted zone is therefore pertinent to the whole Northern Algeria, in terms of seismic hazard and risk establishments. It provides a fundamental means in the mitigation of seismic risk in future disasters by recommending new ways of improving local construction procedures, building material characteristics, strengthening and repairing existing structures, layout and implantation of new urban and rural sites.

However, in order to study earthquakes of the past critically and to understand better the importance of the information contained in the contemporary documents, it is of great usefulness that the political, socio-economic, and demographic conditions, cultural and religious background and building stock characteristics be taken into account. The fact that this event occurred during the Algerian Liberation War period (1954-1962), which was characterized by terror, misery and unemployment, made the shock fall into a second place. This situation presented a real disadvantage in terms of human and property loss evaluation and report; numerous hamlets and douars, scattered in the slope of valleys and flanks of the surrounding mountains and which could have enriched the data, were not mentioned in any contemporary account. The press was prevented to visit the isolated douars and thus to report completely and adequately the extent of damage and the casualty toll. It is certain that in the absence of the war, more attention would have been given to the earthquake and its effects amplified in the documents. We remain doubtful about the number of casualty and extent of damage reported by the accounts available to us; it is reported that this earthquake did cause only few injuries, but no details were given. We believe that many people, caught asleep, were buried under the rubble of their highly vulnerable houses and thus hurt. According to the building stock exposed to this event and the intensity reached, it is clear that the casualty toll and the extent of damage were either underestimated or misreported for some reasons which have been discussed in section 1. Chapter I. We remark that the native people, which constituted about 90 percent of the population in the region, were not mentioned in the contemporary documents. These last two arguments may interpret why human and property losses were disproportionately small. We believe that, for earthquakes occurring during wartime or colonization periods, complete macroseismic data can be retrieved from contemporary military sources which, unfortunately, are not available to us today; because of their official character, this type of documents contains ample and more reliable information.

Summarizing the results, we obtain the following final data for the 8 May 1955 Boucheral earthquake: origin time: 21 h 38 min 59 s (GMT); instrumental epicentre 36.5°N, 1.6°E (ISS); macroseismic epicentre: 36.53°N, 1.46°E; maximum intensity I_0 = VII (MSK); magnitude M_S = 4.75 (± 0.20).

The Beni Rached earthquake of 5 June 1955

Abstract
This research examines one of the destructive earthquakes during this century in the Central Cheliff Valley. The Beni Rached earthquake of 5 June 1955 occurred, at 14 h 56 min 13 s (GMT), very near where earlier shock on 9 September 1954 (M_S = 6.70 (± 0.2)) and later shock on 10 October 1980 (M_S = 7.40 ± 0.30) almost totally destroyed Orléansville and its surrounding villages and douars. The main shock, which lasted for about 6 s, caused important damage in the douar of Beni Rached and its immediate vicinity but there were no injuries or casualties reported among the population. This event occurred, during the seismic crisis of the Orléansville 1954 earthquake which lasted until late 1957, with several foreshocks and followed by many aftershocks which were recorded in the Alger-University seismological station. Detailed analysis of the macroseismic data inferred from different contemporary sources relative to this earthquake, has allowed us to reveal what types of construction existed and what state they were in, and to re-assess intensities in many sites. Poor-quality structures and their bad state were the main cause of the damage. We found no evidence of any sign of ground deformation or liquefaction. Maximum intensity has been re-evaluated at I_0 = VIII (MSK), assigned to Beni Rached and its immediate vicinity. From the intensities thus re-evaluated, an isoseismal map has been constructed and the macroseismic epicentre located, slightly northeast of Beni Rached, at 36.31°N, 1.55°E. The instrumental epicentre has been calculated at 36.3°N, 1.5°E (ISS, 1955). The surface-wave magnitude was computed, without station corrections, at 5.10 (± 0.16).

1. Introduction

On Sunday, 5 June 1955, at 14 h 56 min 13 s (GMT), a destructive earthquake struck the Central Cheliff Valley; it occurred very near where earlier shocks on 9 September 1954 (M_S = 6.70 ± 0.20) and later on 10 October 1980 (M_S = 7.40 ± 0.30) almost totally devastated Orléansville and its surroundings. It took place during the Orléansville 1954 seismic crisis which continued until late 1957; however, it was preceded by several foreshocks and followed by many aftershocks that were recorded in the Alger-University seismological station. The epicentral zone is located at about 170 km west of the capital Alger and on the southern flank of the coastal range Dahra. The main shock, which lasted for about 6 s, destroyed few colonial and local traditional gourbis, and newly affected or extended damage in many. It apparently seems that the earthquake did not cause any injuries or casualties among the population. The radius of perceptibility was relatively small, the shock was felt as east as Fort De L'Eau, south as Tiaret and west as Paul Robert with intensity III$^+$ (MSK), an area of about 104 km radius. The earthquake affected structures within an area of about 45 km radius with intensity V$^+$ (MSK). The main shock was recorded in 98 seismological stations (ISS, 1955), up to 91° away. The instrumental epicentre was computed at 36.3°N, 1.5°E by ISS (1955). We found no evidence any any sign of ground deformation or liquefaction.

In order to re-assess how much damage was inflicted to man-made structures and to the ground itself, and how it was felt by the population, an extensive investigation for contemporary accounts was made in various libraries and archive centres. As a result of this search, it has been revealed that, as in past destructive earthquakes in Algeria and elsewhere, adobe, stone and unreinforced bearing wall structures suffered most damage from cracks to total destruction. Macroseismic data collected has enabled us to disclose the type of constructions that existed, and the state they were in and to re-evaluate intensities at several sites. Maximum intensity has been re-estimated at I_0 = VIII (MSK), assigned to Beni Rached and its close vicinity. From the intensity data, an isoseismal map has been constructed and the macroseismic epicentre located, slightly northeast of the douar of Beni Rached, at 36.31°N, 1.55°E. The surface-wave magnitude was computed, without station corrections, at 5.10 (± 0.16).

2. Sources of information

A considerable search to locate published and unpublished accounts relative to the earthquake, written shortly after the event, was conducted in many libraries and archive centres. The result of this investigation is a collection of contemporary documents, newspapers and technical reports, describing the effects of this event in the region. In spite of its size and the damage it caused, however, there are surprisingly no complete technical report that is known. All the writers have limited their assessment to few line summaries. The main sources used in the study of this earthquake are newspaper reports; the most extensive ones are given in «Le Journal D'Alger» and «La Dépêche Quotidienne» (1955). Benhallou (1985), quoting the archives of the IMPGA as his source, summarized the earthquake in four lines and published an isoseismal map (fig. 1). He assigned maximum intensity I_0 = VIII (MM) to Beni Rached, Kherba and their immediate surroundings.

In the recent catalogues, the instrumental epicentre attributed to this shock is: 36.3°N, 1.5°E (ISS); 36.4°N, 1.6°E (BCIS, 1955; Rothé, 1950; Roussel, 1971); 36.4°N, 1.6°E (Karnik 1969, referring to Grandjean, 1959); 36.5°N, 1.5°E (USCGS) and 36.4°N, 1.7°E (Mezcua and Martinez, 1983). Maximum intensity is evaluated at: VI (MS), (Munuera, 1963); VIII (MS), referring to Grandjean (1959), ISS, USCGS and Karnik (1969); VIII (MM), Roussel (1973); VIII (MM), (Khemici in EERI, 1983); VIII (MM), (Benhallou, 1985) and VI (MSK), (Mezcua and Martinez, 1983). Magnitudes are calculated at: 5.75, MLH = 5.2 (Grandjean, 1959); MLV = 5.4 (Vanek *et al.*, 1960); M_S = 5.2 (Karnik, 1969); 5.7 (Rothé, 1969); 5.5 (Roussel, 1973); 5.5-5.75 (UPP); 5.0 (MOS); 5.75 (STR); M_L = 5.60 (PRA); m_b = 5.0 (Munuera, 1963) and m_b = 4.7 (Mezcua and Martinez, 1983).

3. Geographical aspects of the region

The epicentral area is located in the Central Cheliff Valley which lies within the Tell Atlas mountains at about 170 km west of the capital Alger. It centered on the southern flank of the coastal range Dahra. The Dahra includes in the north a mountainous zone where the height is over 1000 m; the Djebel Bissa is culminating at 1175 m, Djebel Sidi Bernous at 1146 m and Djebel Tkelout at 1041 m.

The Cheliff plain was one of the most important colonization zone in Algeria in terms of population and agriculture, it was densely populated (40 to 60 inhabitants per square km); the douar of Beni Rached counted at that time about 15000 inhabitants (Armature Urbaine 1987, 1988). Ac-

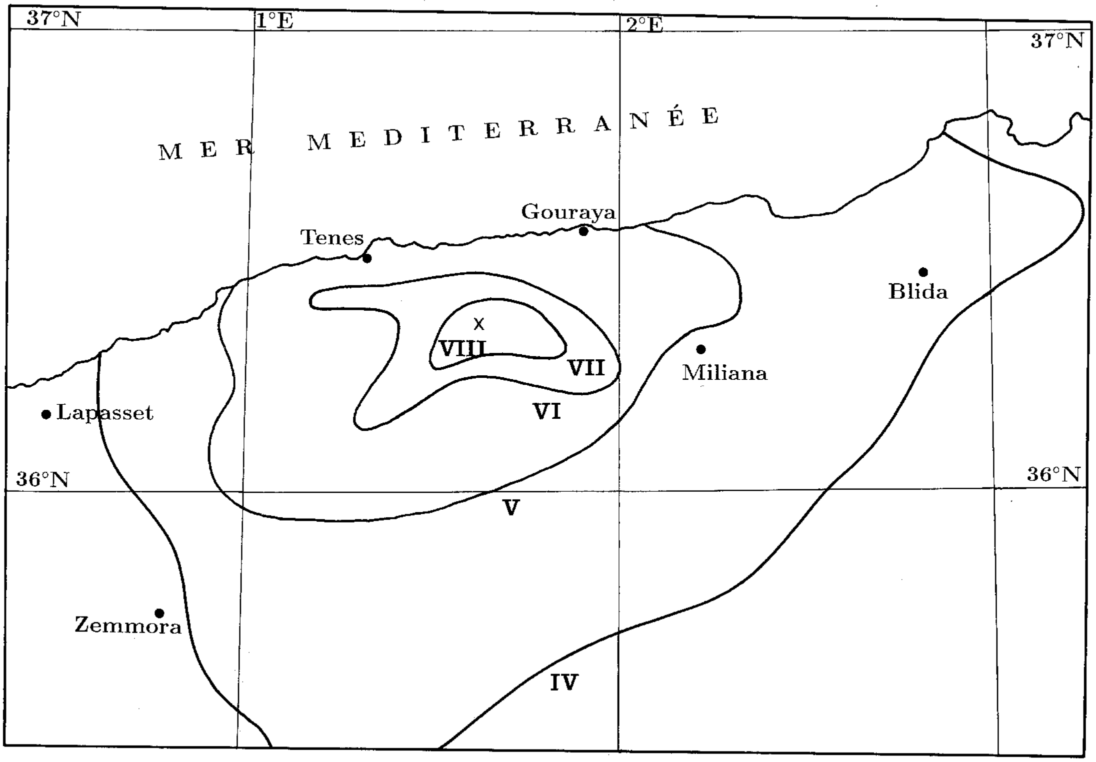

Fig. 1. Isoseismal map (in terms of MM scale) of the main shock of the 5 June 1955 earthquake, after Benhallou (1985). *Redrawn.*

cording to the contemporary documents, apart the official buildings, the public works and the settler houses, most of native algerian dwellings, which experienced destruction or heavy damage during past earthquakes, were of mud-reed, mud-straw, sundried adobe bricks, stone or unreinforced masonry bearing wall constructions. If the colonization centres were located on the lowest gentle slopes or in the plain where water supply is more abundant, the native people douars and hamlets, poorly built, were scattered in the high plateaux or dangerously on the abrupt flanks of the valleys and mountains near small springs. The epicentral area, due to its agricultural vocation, was well equipped with an important public work system, dams, pipes, galleries and several types of canalization, railway and a good road network.

4. Damage and casualty distributions

The Beni Rached earthquake of 5 June 1955 occurred 9 months after that of Orléansville 1954 and less than one month after Boucheral 1955. From the macroseismic data collected, it was revealed that, as in past destructive earthquakes in Algeria and elsewhere, adobe, stone and unreinforced masonry structures sustained most damage. This earthquake destroyed colonial houses and native people gourbis but there were either no report of any injuries or casualties among the population or no communication.

In Beni Rached, a large douar located at about 20 km northeast of Orléansville, the main shock, which lasted 8 s, was strong enough to make people panic and flee their homes, and to cause important damage to the constructions. It completely destroyed 3 colonial houses and 5 gourbis, and added serious damage to the already affected structures during the past earthquakes. Further east in Kherba the shaking, according to witnesses, was felt as strongly as in Beni Rached. Most damage consisted of fall of walls and expansion of existing cracks. In Carnot, a colonial village located at 35 km northeast of Orléansville, the shaking was so strong that people had to flee, all in a flutter, their homes. The shock was compared to that of Orléansville 1954 by the inhabitants. In many houses major damage consisted of small cracks in walls and fall of plaster but no casualties were reported. In Orléansville the shaking was strong enough to make people flee their homes, and to cause new slight damages and worsen existing ones. In Oued Fodda, a small village situated at about 30 km east of Orléansville, the earthquake was felt with equal intensity as Orléansville but no details were given. In Rouina many people were frightened and run outdoors. The shaking was strong enough to cause new cracks and worsen existing ones in many buildings. No casualties were reported. In Les Attafs the main shock was so strong that it caused some cracks and also worsened existing ones in already affected structures during past earthquakes. In Duperre, Ponteba, Warnier, Chasseriau, Hanoteau and Cavaignac, as in the surrounding villages and douars, the earthquake caused new slight cracks and enhanced existing ones from previous shocks. The same degree of shaking, or even less, was experienced in Dupleix, a small colonial village situated at about 30 km north of Beni Rached. The shock caused considerable alarm among the population which had fled their houses but no damage or casualties were communicated. In Cherchell, a coastal town located at 60 km northeast of Beni Rached, the earthquake was violent and preceded by an underground rumbling. It caused panic among the population but no damage or casualties were reported. In Tenes, a small village situated at about 50 km north of Orléansville, the shaking was seriously felt but no damage or casualties were reported. In Marengo the main shock, which lasted for about 10 s, caused considerable concern among the population but no details were communicated. It was preceded by an underground rumbling. In Francis Garnier, Gouraya, Littre, Marceau, Oued Fodda Dam, Charon, Rabelais, Malakoff, and Inkermann, the shock was strong enough to be felt by all the population and some of them run outdoors. No details of damage or casualties were given. Further east at 170 km of Beni Rached, in the capital Alger, an underground rumbling was followed immediately by a shaking which was strong enough to awake abruptly many people from their naps. It was reported that hangings, flower vases, curios on shelves were seen swaying during few seconds. In Fort De l'Eau, Blida, Lodi, Loverdo, Damiette, Miliana, Affreville, Berard, Letourneux, Ammi Moussa, Tiaret, Zemmora and Paul Robert, the shaking was slightly felt but no one was frightened.

5. Intensity re-evaluation

Using the macroseismic data collected from contemporary accounts relative to this earthquake, intensities have been estimated anew with reference to the Medvedev-Sponheuer-Karnik (MSK) scale using standard criteria.

In order to avoid overrating of the ground shaking, an extensive search was made in the attempt to reveal the types of structures that existed at that time and the state they were in. Detailed analysis of these documents shows that the building stock consisted mainly of adobe, stone and unreinforced masonry construction, and few relatively well built reinforced concrete structures. We learned that many of the constructions exposed to this earthquake were in advanced deteriorated state, they suffered through ageing, negligence, rain, improper repairs and particularly earthquakes. After a careful study of the effects of this earthquake, maximum intensity has been re-evaluated at I_0 = VIII (MSK), allocated to Beni Rached and its immediate vicinity. This intensity has been attributed to the zone associated with collapse of structures. Intensity VII-VIII has been allocated to Kherba. Intensity VII has been attributed to Carnot and Cavaignac. Intensity VI-VII has been assigned to Orléansville. Intensity VI has been confined to Rouina, Duperre, Hanoteau, Oued Fodda, Flatters, Chasseriau and Warnier. Intensity V-VI has been allocated to Francis Garnier. Intensity V has been assigned to Tenes, Cherchell, Gouraya, Marceau, Littre, Oued Fodda Dam, Malakoff, Charon, Inkermann, Pointe Rouge and Rabelais. Intensity IV has been allocated to the capital Alger, Miliana and Paul Robert. Intensity III-IV has been confined to Ammi Moussa. Intensity III has been attributed to Fort De L'Eau, Blida, Affreville, Medea, Lodi, Damiette, Loverdo, Letourneux,

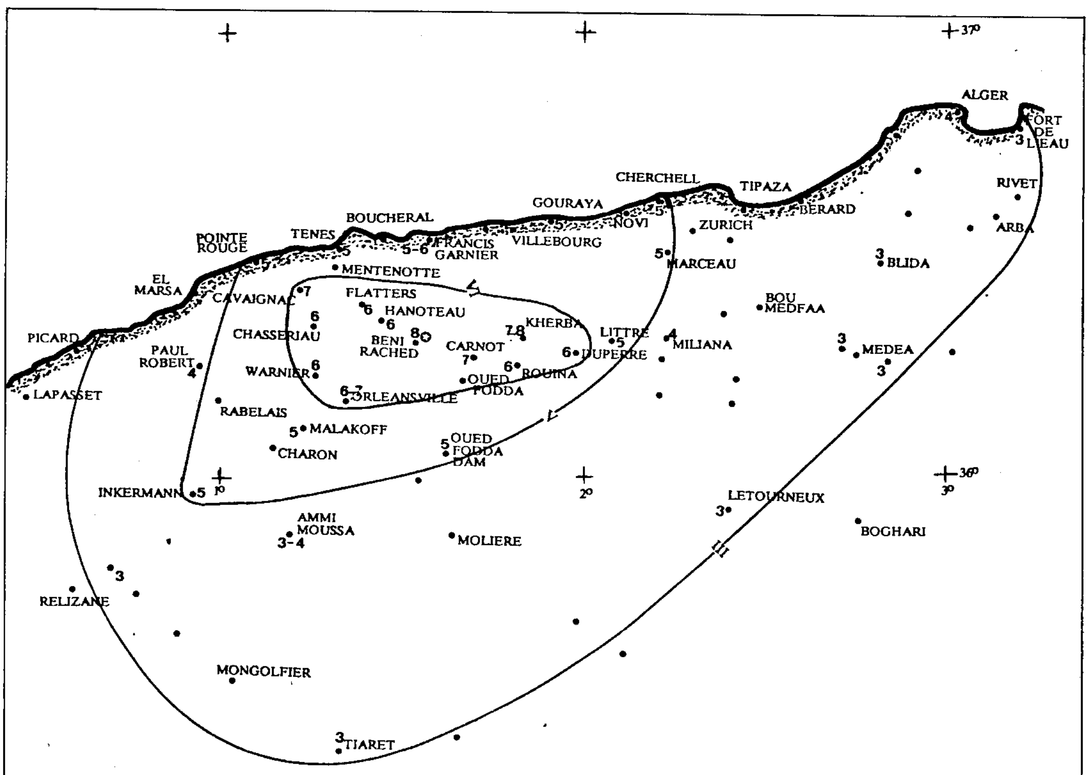

Fig. 2. Isoseismal map (in terms of MSK scale) of the main shock of the 5 June 1955 earthquake. The star shows the macroseismic epicentre of the main shock.

Tiaret and Zemmora. Intensities V through VII have been assigned consistently with a rigid interpretation of the intensity MSK scale (Medvedev *et al.*, 1981). Intensity IV and III have allocated solely on the felt effects and on the evidence of lack of damage to low-quality structures. Intensity III depicts the boundary of the felt area, assumed, in the absence of lower intensity observations. From the intensities thus re-estimated, an isoseismal map of the earthquake has been constructed and is shown in fig. 2.

6. Magnitude determination

The surface-wave magnitude of this earthquake has been calculated from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 4 seismological stations located at distances between 16° and 26° away, and a preliminary epicentre (macroseismic) at 36.31°N, 1.55°E. The data and the results are given in Benouar (1993). The mean period is 11.5 s and the derived value of M_S, without station corrections, is 5.10 ($\pm$ 0.16).

7. Foreshocks and aftershocks

The earthquake was preceded by few foreshocks and followed by many aftershocks. The last foreshock was occurred on 3 June 1955 at 19 h 41 min 52 s (GMT). Nineteen aftershocks were recorded, in the Alger-University station, between the afternoon of Sunday 5 and the morning of Monday 6 June 1955. The largest aftershock occurred on Sunday 5 at about 23 h 7 min (GMT) and was felt as far as Alger with intensity III-IV (MSK).

8. Discussion

The Beni Rached 5 June 1955 earthquake, as that of Francis Garnier 8 May 1955, occurred during the Orléansville 1954 seismic crisis which continued until late 1957 and thus may be taken as a strong aftershock of Orléansville earthquake. However, by its size and the damage it caused, it constitutes one of the most significant earthquakes felt and recorded in the Central Cheliff Valley since the beginning of this century. In terms of seismic history of the region reported by Hée (1950), Rothé (1950), Benhallou and Roussell (1971), Mezcua and Martinez (1983) and recently Benhallou (1985), this shock is by no means an exceptional one.

The study of this earthquake is of great interest for various reasons. Firstly, it represents one of the destructive earthquakes in the Central Cheliff Valley. Secondly, the same epicentral area, which experienced destructive earthquakes in the past, exhibits today many of the humans and geographical characteristics met in other parts of the country. Thirdly, the Cheliff Valley zone, which has been the most seismically active in Algeria, at least during this century, and because it is located very near the capital Alger and Oran (the two largest cities in the country), drew special attention to the urgent needed seismic risk reduction measures in the whole region. For these main reasons, a detailed analysis of the effects of this event in the affected region is therefore pertinent to the whole Northern Algeria, in terms of seismic hazard and risk establishments. This shock, as other destructive ones, greatly contributes in the attenuation of seismic risk by recommending new ways of improving local construction procedures, building material characteristics, strengthening and repairing existing structures, layout and implantation of new urban and rural settlements.

For a better understanding of the information contained in the contemporary documents relative to this event, we have examined all the accounts in the whole context of that period; that is, the political, socio-economic and demographic conditions, cultural, and religious background and the building stock characteristics. The earthquake occurred during the Algerian Liberation War (1954-1962) which was a real disadvantage in terms of reports of its effects in the region. The war had prevented the press and scientists to visit many douars and hamlets, scattered in valleys and flanks of the surrounding mountains, which could have enhanced the macroseismic data. It seems that the war, with the socio-economic conditions which the Algerians were living, made the impression of the shock fall into a second place. It was thought that the information would be abundant, especially in the Algerian and French press, as for the Orléansville 1954 earthquake (before the war). Unfortunately, this was not the case; the information was rather scarce and limited to colonial villages and large douars. It was reported that this shock did cause no injuries or casualties among the population but details were not communicated. No evaluation seems to have been made for the homeless people and cost of damage. We remark that the native people, which constituted more than 90 percent of the inhabitants in the region, were not mentioned in any account. It is true that the information about the native settlements was scarce and that is believed to be due to neglect rather than censorship as it may be thought (Vogt, 1993). The search for additional details, particularly in the native people douars and hamlets, continues.

As for earthquakes and any other type of events occurring during wartime, complete and detailed information can be retrieved from contemporary military sources which, unfortunately, are not available to us today; because of their official character, this type of documentation contains the most reliable data.

Summarizing the results, we obtain the following final data for the 5 June 1955 Beni Rached earthquake: origin time: 14 h 56 min 13 s (GMT); instrumental epicentre 36.3°N, 1.5°E (ISS); macroseismic epicentre 36.31°N, 1.55°E; maximum intensity I_0 = VIII (MSK); magnitude M_S = 5.10 (± 0.16).

The Bou Medfaa earthquake of 7 November 1959

Abstract

This work presents one of the largest felt and recorded earthquakes that occurred in the Sahel of Alger. The Bou Medfaa earthquake of 7 November 1959 occurred at 2 h 32 min 7 s (GMT); it is one of the destructive seismic events that central Algeria has experienced. The main shock, which lasted 8 s, caused, by miracle as reported, only two injuries and making at least 500 homeless; it destroyed or heavily damaged more than 80 percent of the houses, farms and public buildings in Bou Medfaa and its close surroundings. Poor-quality constructions were the main cause of the damage. The total cost of damage was estimated at 300 million French Francs. The earthquake was preceded by two slight foreshocks and followed by a series of much less intensity aftershocks. It was associated with a slight surface ground fissure in Bou Medfaa. Detailed study of the macroseismic information has led to re-evaluate intensities in different sites. Maximum intensity was re-estimated at I_0 = VIII (MSK), assigned to Bou Medfaa, Hammam Righa and Ameur El Ain, an area of about 8 km radius. The shock was felt as far as Dellys 150 km away with intensity III. From the intensity data, the macroseismic epicentre was located slightly north of Bou Medfaa at 36.41°N, 2.48°E. The surface-wave magnitude was calculated, without station corrections, at 4.90 (± 0.4).

1. Introduction

On the 7th of November 1959 at 2 h 32 min 7 s (GMT), a destructive earthquake hit the region of Bou Medfaa. The area most affected lies on the Zaccar ranges at about 65 km southwest of the capital Alger. The same epicentral region has been affected many times since the beginning of this century (1922, 1924, 1934, 1937, 1954).

The main shock, which lasted 8 s, caused the destruction of about 80 percent of the houses, farms and public buildings in Bou Medfaa, Hammam Righa, Ameur El Ain and their close surroundings. It produced significant cracks in two bridges in the region. By miracle, as it was reported and according to the extent of the damage, the earthquake caused only two injuries and making 500 homeless. The earthquake affected structures in an area of about 40 km radius with intensity V^+ (MSK). The event was associated with a slight surface ground rupture in the vicinity of Bou Medfaa. The total cost of the damage produced was estimated at 300 million French Francs. It was felt, in a fairly large area, as far east as Dellys, west as Tenes and south as Bourbaki, an area of about 27000 square km. The main shock was preceded by two slight foreshocks and followed by a series of much less intensity aftershocks which did not cause any further damage but seriously undermined the spirits of the population. It was reported that, about half hour before the main shock, the animals became uneasy and many of the livestock fled from the stalls and so escaped death. The compilation and critical consideration of the macroseismic data collected, from various contemporary documents, has led to the re-evaluation of intensities in many sites and the drawing of an isoseismal map. Maximum intensity was re-estimated at I_0 = VIII (MSK), and has been allocated to Bou Medfaa, Hammam Righa, Ameur El Ain and their surroundings, an area of about 8 km radius. From these intensity data, the macroseismic epicentre was relocated slightly north of Bou Medfaa, at 36.41°N, 2.48°E. The main shock was widely recorded by many seismological stations. The surface-wave magnitude was calculated, without station corrections, at 4.90 (± 0.4).

2. Sources of information

In order to reconstruct the macroseismic field of this earthquake with a certain degree of reliability, an important search for contemporary documents relative to the event was carried out in different libraries. This seismic event was widely commented in the Algerian and French press (1959). The most extensive accounts are given in «L'Echo D'Alger» which contains detailed macroseismic information accompanied with a great number of photographs which show clearly the extent of the damage caused to the structures. In spite of its significance in the region, however, there is surprisingly no detailed scientific study of

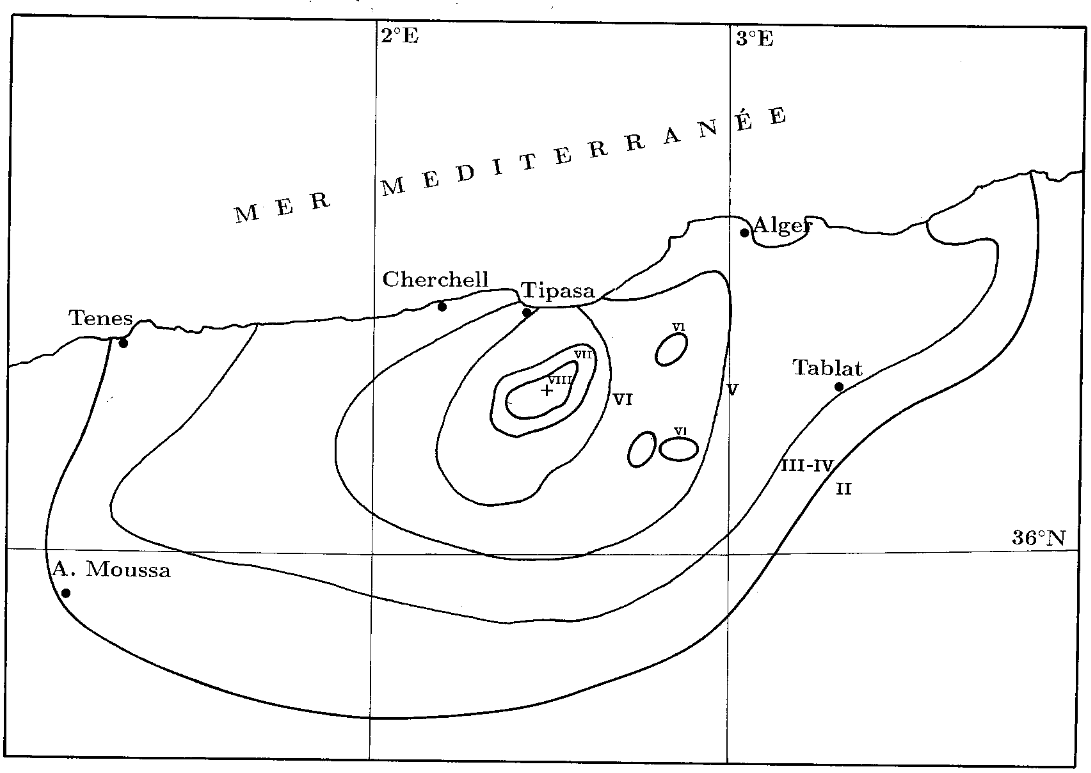

Fig. 1. Isoseismal map (in terms of MS scale) of the main shock of the 7 November 1959 earthquake, after Benhallou (1985). *Redrawn.*

this event that is known. The lack of information is mainly due to the fact that the earthquake coincided with the Algerian Liberation War. Rothé (1969) summarized in few lines the earthquake, without quoting his sources, located the macroseismic epicentre at 36.4°N, 2.5°E and attributed class (d) to the earthquake. An overview of the event was realized by Benhallou and Roussel (1971); they assigned maximum intensity at I_0 = VIII-IX in the Mercalli intensity scale to Bou Medfaa. Their work is distinguished by the fact that they used data from primary sources of information (questionnaire in the IMPGA). Benhallou (1985) summarized briefly the damage of the earthquake and published an isoseismal map (fig. 1). Mezcua and Martinez (1983), referring to the IPGA, allocated maximum intensity at IX (MSK) to Bou Medfaa and assigned a body-wave magnitude at 5.1. The macroseismic epicentre was located at 36.4°N, 2.5°E (IPGA and BCIS). The instrumental epicentre was located at 36.5°N, 2.5°E (USCGS and URSS) and 36.39°N, 2.50°E (ISS). The magnitude was calculated at 5.5 (Roussel, 1973 and Rothé, 1969); 5.5-5.75 (MAT); 5 (MOS) and 4.75-5 (PRU).

3. Geographical aspects of the region

The epicentral zone of the Bou Medfaa 7 November 1959 earthquake lies, at about 65 km southwest of the capital Alger, on the southern side of the coastal ranges of Dahra-Zaccar. The epicentre is located between Djebel (Mount) Zaccar (east of Miliana), which culminates at 1580 m, and the Blidean atlas (Tamesguida 1604 m). The Zaccar forms the oriental limit of the Dahra ranges (Bernard, 1929; Houston, 1964). Bou Medfaa is a large douar where the local houses consisted mainly of mud-reed, mud-straw or stone bearing walls with thick clay or lime mortar joints and covered with a heavy roof. Hammam Righa is a well known hot spring spa in the region, it is located on the eastern flank of the Zaccar at about 980 m high. Many other native Algerian douars and hamlets, poorly built, were sparsely distributed in the small high plateaux or dangerously perched on the abrupt slopes of the surrounding valleys, generally near small springs which are used for their daily needs as well as for the irrigation of their vegetable gardens. The douars were densely populated, with about 40 to 60 inhabitants per square km (Armature Urbaine 1987, 1988).

4. Damage and casualty distributions

The macroseismic information retrieved from all the sources available to us were carefully analyzed and then used in the estimation of the amount of damage caused to man-made structures and to nature, and how the shock was felt in many localities. We remarked that, as in past earthquakes in Algeria, adobe, stone and unreinforced masonry buildings totally collapsed or experienced heavy damage. Regarding to the size of the earthquake, the time of occurrence, and the low-quality and bad state of the structures, it is very amazing that only two people were injured and 500 homeless. The earthquake caused total destruction or heavy damage to most of the constructions in the area containing the villages of Bou Medfaa, Hammam Righa and Ameur El Ain.

In Bou Medfaa, a small colonial village located on the Zaccar ranges, the shaking, which lasted 8 s, was so strong that all the population, abruptly awakened all in a flutter, fled from their homes despite the curfew. The main shock rendered at least 80 percent of the houses uninhabitable (Press Reports, 1959). Although the population did not report any foreshock, two foreshocks were recorded on 6 November at the seismological station of Alger-University (ALG). In the other hand, witness accounts described the night of the earthquake as: «... That night the cries of the animals were remarkably lugubrious. Dogs, all in panic, rushed in the streets and were howling death, cows mooed desperately and were very unease in the stalls and poultry was all in emotion. Followed about half hour later by a deafening underground rumbling and then a violent shaking which abruptly awakened all the population of the region. The screaming of women and children, the total darkness, and the noise and the dust of the crashing structures turned the night into a veritable inferno...». Most of the houses, which look apparently slightly damaged from the exterior, were rendered uninhabitable by the collapse of the partition walls and ceilings. It was really in the interior of the constructions where one could measure the extent of the disaster: inner walls and ceilings collapsed, roofs destroyed, floors uplifted and seriously fissured, and furniture jumbled. Homeless families gathered outside their house waiting for relief. The health centre, a recent construction, was severely damaged. The gendarmerie was so damaged that all the gendarme families were transferred to Miliana and Hammam Righa. The town hall was also heavily damaged. The Security and Administrative Service (SAS) army barracks were completely destroyed. The Church Saint-Jean sustained significant damage. Farms, very near Bou Medfaa, were totally destroyed and by miracle, as it is reported, their occupants and livestock were saved from death and injury. A hangar with relatively thick stone walls collapsed. Many people were reported to have been buried under the rubles of their houses, but details were either not reported or not communicated. The school which was a precast construction did not sustain any damage. The post office was apparently not affected. Tombstones overturned. The telephone lines were disrupted. In Hammam Righa, a hot springs village, located at 6 km west of Bou Medfaa, the shock was so strong to awake the population and make them flee from their homes. The Grand hotel sustained so much damage that it had to be completely evacuated. The damage consisted of fall of chimneys, major fissures in the walls, displacement of furniture and objects. In Ameur El Ain, a small village located at 14 km north of Bou Medfaa, the earthquake was strongly felt. The population, abruptly awakened, fled from their homes to the streets and public gardens. The damaged was summarized as fall of chimneys, deep cracks in walls and displacement of furniture and objects. The post office was partly destroyed. In Oued Djer, a very small village located at 20 km northeast of Bou Medfaa, the deck of the bridge was fissured and uplifted at the junction with the beams, as if the shaking was from bottom to top. Major cracks in the ceilings and walls, displacement of furniture, breaking of dishes and glasses, fall of tiles and the ringing of bells were the main effects on the structures. It is important to mention that the details of the damage were not mentioned in any contemporary document. In Affreville, El Affroun and Vessoul-Benian, the same scenes as in Oued Djer, where most damage consisted of cracks in partition walls and ceilings and fall of tiles. In Ain N'Sour, Ain Sultan, Beni Mered, Affreville, Bourkika, Changarnier, Miliana, Joinville, Lavigerie, Le Puits, Loverdo, Marengo, Marguerite, Meurad, Montebello, Tipaza and Trolard-Taza, the shaking awakened most people and many of them run outdoors. The damage consisted of small cracks in walls and chimneys. The furniture was displaced and the bells rang. In Benchicao, Douera, Lavarande, Palestro, Attatba, Berard, Blida, Bouinan, Desaix, Duperre, Gouraya, Lodi, Miliana, Mouzaiaville, Oued El Alleug and Zurich, the shaking awakened many people. Many walls in adobe and stone houses were slightly cracked. The details of the damage were not published. In Alger, Cap Matifou, Ain Taya, Alma, Beni Amran, Birtouta, Boufarik, Castiglione, Chebli, Dalmatie, Damiette, Douaouda, El Achour, Felix Faure, Fondouk, Fouka Marine, Ghrib Dam, Guyotville, Hamiz, Kherba, La Chiffa, Le Corso, Le Vacher, Maison Carree, Rouiba, Rovigo, Saoula, Staoueli, Villebourg and Zeralda, the shaking awakened few people. It was reported that windows, doors, furniture and dishes were shaken, and floors and walls were cracking. In Arba, Bellefontaine, Birkadem, Boghar, Boghari, Bordj Menaiel, Bougainville, Cap Caxine, Carnot, Cheraga, Cherchell, Crescia, Dra El Mizan, Dupleix, El Khemis, Kolea, Hussein Dey, Les Attafs, Letourneux, Mahelma, Maison Blanche, Marechal Foch, Massena, Menerville, Novi, Oued Fodda, Reberal, Reghaia, Rivet, Rouina, Souk El Had and Theniet El Had, the shaking was felt indoors only by few people. The shaking was reported as scarcely felt by people at rest indoors in Arthur, Courbet, Haussonvillers, Lamartine, Marbot, Orléansville, Saint Pierre - Saint Paul, Sidi Moussa, Tablat, Thiers, Ammi Moussa, Bourbaki, Cap Tenes, Chasseriau, El Alef, Flatters, Inkermann and Moliere.

5. Intensity re-evaluation

Intensities were re-estimated, using the macroseismic data collected from a variety of contemporary documents, with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale. For a better re-evaluation of the strength of the ground shaking, a comprehensive search was realized in the aim to reveal the different types of constructions that existed at that time and the state they were in. Detailed study of these documents shows that the building stock was mainly constituted of adobe, stone and unreinforced masonry structures. It is revealed that many of these houses were in a bad state as they suffered deterioration through ageing, negligence, rain, improper repair and particularly earthquakes. Most of these houses were seriously affected by the earthquakes that occurred in the region and particularly by the Orléansville 1954 earthquake.

As a consequence of the very low strength and high vulnerability of these structures, the maximum intensity in any destructive earthquake in the douars of the region seems to be the same. That is, at intensity IX in the MSK scale, most of the houses are totally destroyed and any douar or old colonial village would therefore look equally, but no more, devastated at higher intensities of the scale.

After a detailed analysis of the macroseismic data, maximum intensity was re-estimated at I_0 = VIII (MSK) and allocated to Bou Medfaa, Hammam Righa and Ameur El Ain, an area of about 8 km radius. Maximum intensity was assigned to the zone associated with maximum damage to structures and injuries. Intensity VII was attributed to Oued Djer, Affreville, El Affroun and Vessoul-Benian. Intensity VI was confined to Ain N'Sour, Ain Sultan, Beni Merad, Affreville, Bourkika, Changarnier, Miliana, Joinville, Lavigerie, Le Puits, Loverdo, Marengo, Margueritte, Meurad, Montebello, Tipaza and Trolard-Taza. Intensity V was allocated to Benchicao, Douera, Lavarande, Palestro, Attatba, Berard, Blida, Bouinan, Desaix, Duperre, Gouraya, Lodi, Mouzaiaville, Oued El Alleug and Zurich. Intensities V through VII were assigned consistently with a rigid interpretation of the intensity MSK scale (Medvedev *et al.*, 1981). Intensity IV was attributed to Alger, Ain Taya, Alma, Beni Amran, Birtouta, Boufarik, Cap Matifou, Castiglione, Chebli, Dalmatie, Damiette, Douaouda, El Achour, Felix Faure, Fondouk, Fouka Marine, Ghrib Dam, Guyotville, Hamiz, Kherba, La Chiffa, Le Corso, Levacher, Maison Carree, Rouiba, Rovigo, Saoula, Staoueli, Villebourg and Zeralda. Intensity III was assigned to Arba, Bellefontaine, Birkadem, Boghar, Boghari, Bordj Menaiel, Bougainville, Cap Caxine, Carnot, Cheraga, Cherchell, Crescia, Dra El Mizan, Dupleix, El Khemis, Kolea, Les Attafs, Letourneux, Mahelma, Maison Blanche, Marechal Foch, Massena, Menerville, Novi, Oued Fodda, Reberal, Reghaia, Rivet, Rouina, Souk El Had and Theniet El Had. Intensity II was confined to Arthur, Courbet, Haussonvilliers, Lamartine, Marbot, Orléansville, Saint Pierre - Saint Paul, Sidi Moussa, Tablat, Thiers, Ammi Moussa, Bourbaki, Cap

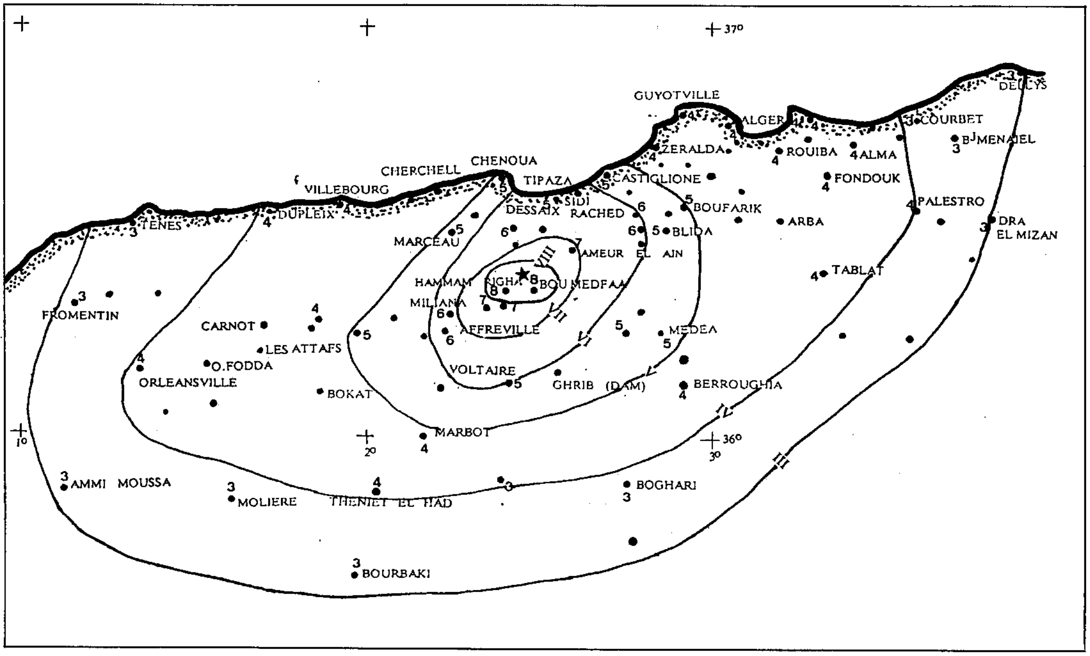

Fig. 2. Isoseismal map (in terms of MSK scale) of the main shock of the 7 November 1959 earthquake. The star shows the macroseismic epicentre of the main shock.

Tenes, Chasseriau, El Alef, Flatters, Inkermann and Moliere. Intensities II through IV were allocated solely on the felt effects and on the evidence of lack of damage to poor-quality constructions.

As a result of the analysis of the macroseismic data available, an isoseismal map of Bou Medfaa 7 November 1959 earthquake has been drawn and is shown in fig. 2.

6. Magnitude determination

The surface-wave magnitude of the earthquake has been calculated from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 12 seismological stations located at distances between 12° and 33° and a preliminary epicentre (macroseismic) at 36.41°N, 2.48°E. The data and the result and shown in Benouar (1993). The mean period is 14 s and the derived value of M_S, without station corrections, is 4.90 (± 0.4).

7. Teleseismic relocation

The instrumental epicentre of the earthquake has been determined by using the present location procedure of the International Seismological Centre (ISC) and readings from 86 stations which reported the event to the ISS. The main shock was recorded through Europe as far Sverdlovsk 44° away, Africa as Broken Hill 56°, south pole as Scott Base 138° and Australia as Charters Towers 144°; the closest station being Relizane 1.8° southwest of the epicentre. Stations with large residuals have been weighed small or left out the analysis.

Using the actual location ISC procedure and a trial origin at 36.390°N, 2.500°E, we find:

1959 November 7
2 h 32 min 7 s (± 0.37)
36.38°N (± 0.042), 2.55°E (± 0.047)
Shallow focus 2 km.

This position agrees with the macroseismic epicentre with errors of about 3 km in latitude and 7 km in longitude.

8. Foreshocks and aftershocks

Although not felt by the population of the affected zone, two foreshocks, which occurred on 6 November at 3 h 54 min and 11 h 45 min (GMT), were recorded in the Alger-University station (ALG). These premonitory shocks may explain the particular behaviour of the animals on the night of 6 to 7 November in the Bou Medfaa region.

The main shock was followed by eight slight aftershocks recorded at the Alger-University station, continuing until 13 November 1959. These aftershocks, with much less intensity than that of the main shock, did not cause any further damage but seriously undermined the spirits of the population.

9. Discussion

The 7 November 1959 Bou Medfaa earthquake is one of the largest seismic events felt and recorded in the coastal zone between Alger and Cherchell. In terms of the seismic history of the region reported by Hée (1933 and 1950), Rothé (1950), Benhallou and Roussel (1971), Mezcua and Martinez (1983), Benhallou (1985), and Ambraseys and Vogt (1988), it was by no means an unattended earthquake. In fact, Bou Medfaa sustained major damage during many past earthquakes and particularly on 19 July 1937 Bou Medfaa, which destroyed most of the constructions, and 9 September 1954 Orléansville earthquakes. The reconstruction of the macroseismic field of this event is of great importance for many reasons. First, it represents one of the strongest felt and recorded earthquake in Bou Medfaa and its vicinity. Second, the same epicentral area, which experienced destructive earthquakes in the past, exhibits today many human and geographical characteristics found in different other regions of the country. For these main reasons, a detailed study and analysis of the effects of this earthquake on the region are therefore relevant to the whole of Northern Algeria, in terms of seismic hazard and risk evaluations. They contribute substantially in the reduction of seismic risk by suggesting new ways of improving local construction procedures, building material characteristics, strengthening and repairing existing structures, layout and implantation of new urban and rural sites. Critical examination of the collected data has allowed us to re-evaluate the extent of damage produced, the behaviour of the people and thus the intensities. However, we should keep in mind that the majority of the damage was sustained by adobe, stone and unreinforced constructions which were predominant in the region. Maximum intensity was re-estimated at VIII (MSK) and assigned to Bou Medfaa, Hammam Righa and Ameur El Ain, an area of about 200 square km. From the intensity data, the macroseismic epicentre was located slightly north of Bou Medfaa, at 36.41°N, 2.48°E. On the other hand, for a better understanding of the information contained in contemporary documents, we have considered the accounts in the whole context of the period concerned; that is, the political, socio-economic and demographic conditions, cultural and religious backgrounds and the characteristics of the building stock exposed to the shaking. The earthquake occurred in the middle of the Algerian Liberation War (1954-1962) which was very active in the Zaccar ranges. The fact that this event coincided with the war period was a real disadvantage in terms of human and property loss reports; numerous douars sparsely distributed in the valleys and flanks of the surrounding mountains, which could have substantially enriched the data, were not mentioned in any contemporary document. This particular situation prevented the press to visit the isolated villages, douars and hamlets and report correctly the effects of the earthquake. In fact, the war and the precarious socio-economic conditions which the Algerians were living made the impression of the shock fall into a second place. The information in the press is rather scarce, repetitive and concentrated mainly on the village of Bou Medfaa. It was reported that only two children were injured and 500 rendered homeless. We believe that many people, caught asleep in very poor-quality houses, were buried under the rubles of their homes and thus hurt. A detailed study of the macroseismic data and particularly the photographs published, show that the casualty toll and damage were either underestimated or for some reasons misreported. The lack of information about the native Algerians is discussed in section 1. Chapter I. In fact, as in previous events of any kind the French authorities reported the effects in a better way to show stability and security for the settlers. We remarked that the native Algerians, which constituted 90 percent of the population, were not really mentioned in any document. These last arguments may explain the reasons that human and property losses were disproportionately small for adobe and stone houses. It is probable that in the absence of war, more attention would have given to the earthquake and its effects widely reported.

We believe, as for other events in war situations, more information can be inferred from contemporary military sources which are not available to us today; because of their official character, this type of document contains the most reliable information.

Summarizing the results, we obtain the following final data for the 7 November 1959 earthquake: origin time 2 h 32 min 7 s (GMT); instrumental epicentre 36.38°N, 2.55°E; macroseismic epicentre 36.41°N, 2.48°E; focal depth about 4 km; maximum intensity I_0 = VIII (MSK); magnitude $M_S = 4.90$ (± 0.4).

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The Oran earthquake of 12 December 1959

Abstract
This research presents the earthquake that occurred on 12 December 1959 in Central Western Algeria on the shores of the Mediterranean Sea. The 12 December 1959 Oran earthquake occurred, without a foreshock, at 20 h 0 min 5 s (GMT) and was followed 10 min later by the first aftershock. It constitutes one of the most destructive seismic event in this region since the beginning of this century. The main shock, which lasted between 6 and 10 s, produced significant damage from moderate to slight cracks in old buildings and caused considerable concern among the population within the plain of Sebkha. The epicentral zone, which centred between the town of Oran and the village Kristel, is located at 350 km west of the capital Alger. The earthquake produced a slight ground surface fissures but no sign of liquefaction was found. The main shock was followed by several aftershocks, continuing until late January 1960. It was recorded by many seismological stations in the world. The instrumental epicentre of the main shock was calculated at 35.72°N, 0.56°W by the ISS (1959). Collection and analysis of the macroseismic information retrieved, from contemporary accounts, have led to the re-evaluation of intensities in several sites and to the construction of an isoseismal map of the earthquake. Maximum intensity has been re-estimated at I_0 = VII (MSK), allocated to the area contained between Oran and Kristel, a zone of about 11 km radius. The shaking was felt as far as Tlemcen 110 km away with intensity III$^+$ (MSK). From the intensity data, the macroseismic epicentre has been located, on the coast between Oran and Kristel, at 35.75°N, 0.53°W. The surface-wave magnitude was computed, without station corrections, at 4.55 (± 0.11).

1. Introduction

On Saturday the 12th of December 1959, at 20 h 0 min 5 s (GMT), the coastal region of Oran was struck by a destructive earthquake. The epicentral zone, which centred between Oran and Kristel, is situated at 350 km west of the capital Alger. The main shock, which lasted between 6 and 10 s, was strongly felt in Oran, Kristel, Saint-Cloud and their immediate surroundings where it caused considerable alarm but no important damage. Most damage consisted of cracks in walls and fall of plaster in old buildings. The earthquake produced a small ground surface fissure (35 cm wide and several metre long) and broken a water pipe, but there were no sign of liquefaction. The main shock was felt as far west as Tlemcen, east as Lapasset and south as Matemore, with intensity III$^+$ (MSK). It affected structures, with intensity V$^+$ (MSK), within an area of about 33 km radius. The main shock, which occurred without a foreshock, was followed by several aftershocks continuing until late January 1960. The earthquake was recorded in many seismological stations in the world. The ISS (1959) had calculated the instrumental epicentre of the main shock at 35.72°N, 0.56°W.

In terms of seismic history of the region reported by Hée (1925, 1933), Rothé

(1950, 1969), Benhallou and Roussel (1971), Mezcua and Martinez (1983) and Benhallou (1985), the same epicentral zone has experienced many destructive earthquakes in the past, thus this event is by no means an unattended one. The 1959 Oran earthquake occurred very near where an earlier shock on 9 October 1790 which totally destroyed Oran with the loss of 3000 lives.

Compilation and careful analysis of the contemporary accounts relative to this event have led to detailed re-assessment of how much damage was produced to manmade objects and to nature, and how it was felt by the population. As the result of this investigation, intensities have been re-estimated at many sites and an isoseismal map of the earthquake has been constructed. Maximum intensity has been re-evaluated at I_0 = VII (MSK), assigned to the coastal zone containing Oran, Saint-Cloud, Kristel and their immediate surroundings, and covers an area of about 11 km radius. From the intensity data, the macroseismic epicentre has been located, slightly northeast of Oran, at 35.75°N, 0.53°W. The surface-wave magnitude has been computed, without station corrections, at 4.55 (± 0.11).

2. Sources of information

The Oran earthquake of 12 December 1959 is one of the most significant seismic events in Western Algeria, not only because it caused damage, but because of its occurrence in one of the most densely populated zone in Algeria. In fact, Oran is the second largest town in the country and accommodated in 1959 about 300000 (Armature Urbaine 1987, 1988).

For the purpose of reconstructing the macroseismic data of this earthquake, an extensive investigation for contemporary documents was carried out in many libraries and archives. The result of this is mainly a collection of Algerian and French newspaper reports. Despite its significance, we found no complete technical report that is really known. It was believed that the information would be ample, particularly, in the press as for past destructive earthquakes. Unfortunately, this was not so; the information either in the press or in the brief summary reports were rather scarce and limited to colonial towns and villages. In the press, the most extensive accounts were given in «Le Journal D'Alger» and «L'Echo D'Oran» (1959). Among the brief reports available to us, the most significant is that of Benhallou and Roussell (1971) which summarized the effects of the earthquake and assigned intensities in many sites. Their work is distinguished by the fact that, regardless of the details of the evaluation procedure adopted, the basic data have been established from primary sources of information. Benhallou (1985), quoting the archives of the IMPGA and his previous work, assigned intensities in many villages and published an isoseismal map of the event (fig. 1).

In the recent catalogues, the instrumental epicentre of this earthquake was located at: 35.72°N, 0.56°W (ISS, 1959); 35.8°N, 0.6°W (IMPGA and BCIS, 1959); 35.7°N, 0.6°W (Rothé, 1969); 35.8°N, 0.6°W (Benhallou and Roussel, 1971; Mezcua and Martinez, 1983). Maximum intensity was assigned at: VII (MM), (IMPGA and BCIS, 1959; Benhallou and Roussel, 1971; Benhallou, 1985) and VII (MSK), (Mezcua and Martinez, 1983). Magnitudes were calculated at m_b = 4.3 (Mezcua and Martinez, 1983).

3. Geographical aspects of the region

The epicentral zone lies within the plain of Sebkha which is at 350 km west of the capital Alger. It centred at about 12 km northeast of Oran, the second largest city in Algeria which was accommodating about 300000 people at the time of the earthquake.

In contrast to Eastern Algeria, the Tell in the western part is generally less elevated, less watered (rain) and poorly

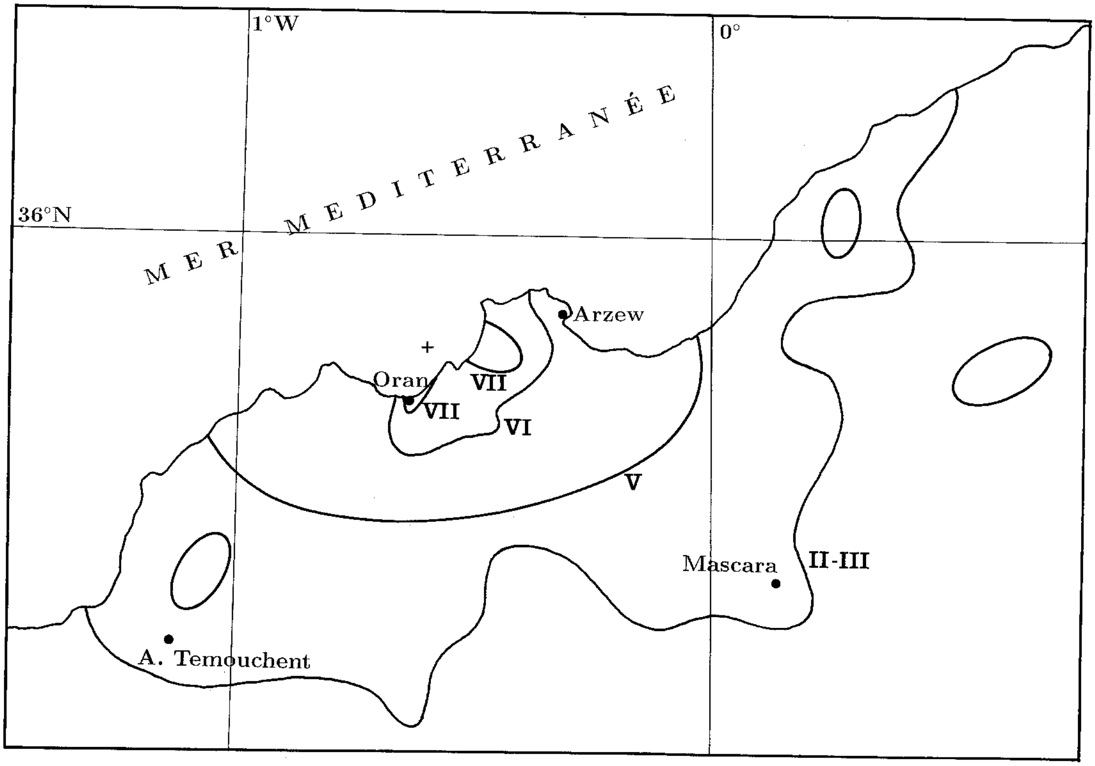

Fig. 1. Isoseismal map (in terms of MM scale) of the main shock of the 12 December 1959 earthquake, after Benhallou (1985). *Redrawn.*

wooded. The littoral massifs in this region, which are constituted mainly of limestones and clays more or less schistose, are limited in the south by a series of low plains. The Sahel of Oran contains abrupt peaks such as the massif of Murdjadjo (581 m) and Djebel Ourouze (631 m) and is surrounded by more recent and less broken ground within which were formed the Oran and Arzew bays. The plain of Sebkha, of which the centre is occupied by a stagnant lac, is limited in the south by the Tell Atlas mountains, merges in the east in the Perregaux plain and continues in the west in the Ain-Temouchent plain. According to contemporary sources of that period, it is revealed that most of the native people were living in low-quality houses made of adobe or stone with heavy thatched roofs and French settlers in better built constructions varying from unreinforced masonry and stone bearing walls to reinforced concrete structures. This region, in spite of the frequency of its salted soils and marshy grounds which are less adequate to cultivation, was highly colonized mainly because of its vicinity to the town of Oran.

4. Damage and casualty distribution

The results of the study and analysis of contemporary documents relative to this earthquake have considerably contributed to the re-assessment of how much damage was sustained by man-made structures, and by nature and how the population behaved. The maximum effects of the earthquake were experienced within a zone along the coast between Oran and Kristel, where a considerable number of old houses had seen their walls and ceilings cracked. The earthquake did not cause any injuries or casualties among the population, as it was reported in the contemporary accounts available to us.

In Oran itself, the main shock, which lasted between 6 and 10 s, was strong enough to cause considerable panic among the population particularly in the modern high rise buildings (18 to 20 storeys). Most of the inhabitants of the city were frightened and fled their homes to the streets and public gardens. An account from the town reported a phrase of a little scared boy saying to his mother: «... Mummy, retain these shaking walls, I beseech you...». For more than one hour, after the main shock, people were in full alert in the streets waiting for stronger shocks. The shaking, which was accompanied with a deafening underground rumbling, was first characterized by a vertical oscillation from top to bottom and then followed by others in the north-south direction. Maximum damage consisted of cracks in walls and ceilings in old buildings and a deep and serious fissure in a wall of a garage. The most impressive sight left behind the earthquake is the large fissure on the ground surface (30 cm wide and several metres long) in the Boulevard Sebastopol which was closed to traffic. In the apartments, lustres were swaying after the shaking with a amplitude at the base of about 10 cm and furniture displaced. Two families in the rue Dresdes, of which the houses were threatening of collapse, were evacuated and given shelter. The shock caused damage in most of the parts of the city. In Saint Charles and Saint Eugene dishes fastened to walls had fallen, and in Gambetta and Victor Hugo walls were cracked and a water pipe broken. In Saint Cloud, a colonial village located at about 20 km east of Oran, the main shock was felt as strong as in Oran; most of the people were frightened and had run outdoors. Damage consisted of cracks in walls and ceilings of old houses. Strongly felt in Kristel, a colonial village situated at 20 km northeast of Oran, where it caused people to flee their homes to the open, cracks in walls and ceilings, and displacement of furniture. In Marechal Leclerc, a colonial village located at 40 km southeast of Oran, the shock was strong enough to cause cracks in a house near the train station. The shaking, which was accompanied with an underground rumbling, was seriously felt in Bou Sfer 15 km west of Oran but no damage or casualties among the population were reported. The main shock was strong enough to cause considerable fear among the population of which many ran outdoors and produce slight cracks in walls and ceilings in La Senia, Hassi Ameur, Mers El Kebir, Hassi Ben Okba, Hassi El Biod, Hassi Bou Nif, Arcole, Sidi Chami and Boufatis. The earthquake was seriously felt by all the people and only few fled their homes but there were no damage or casualties among the population in Bou Sfer, Valmy, Sainte Barbe du Tlelat, Pointe de L'Aiguille, Fleurus, Arzew, Ain El Turck, Bou Tlelis and Saint Leu. In the colonial villages of Mostaganem, Pont du Chelif, Perregaux, Saint Lucien, Saint Denis du Sig, Sidi Bakhti, Turgot and Tounin, the shock was felt indoors by many people and outdoors by a few but no damage was observed. In Tlemcen, Sidi Bel Abbes, Ain Temouchent, Mascara, Lapasset, Bougirat, Dublineau, Saint Maur, Hammam Bouhadjar, Relizane, Bou Hanifia, Matemore, Trois Marabouts, Cassaigne, Sirat, Laferriere, Nouvion, Tizi, Mercier Lacombe, Rivoli, Ain El Arba, Cap Figalo and Maoussa, the shaking was weak and partially felt.

5. Intensity re-evaluation

Using all the macroseismic information inferred from contemporary documentary materials, relative to this earthquake, available to us, intensities were re-estimated with reference to the Medvedev-Sponheuer-Karnik (MSK) intensity scale.

Careful consideration and analysis of the macroseismic data collected have allowed us to re-evaluate intensities in many sites in the affected region. Maximum intensity has been re-assessed at I_0 = VII (MSK). The area of maximum intensity, which involves a zone of approximately 11 km radius, is centred slightly east of Oran. It covers the town of Oran, the villages of Kristel and Saint Cloud and their immediate vicinities. Broadly, maximum intensity has been allocated to the zone associated with moderate damage as cracks in walls, and ceilings and fall of plaster. Intensity VI has been assigned to La Senia, Hassi Ameur, Mers El Kebir, Hassi Ben Okba, Hassi El Biod, Hassi Bou Nif, Sidi Chami and Boufatis. Intensity V has been confined to Bou Sfer, Marechal Leclerc, Valmy, Sainte Barbe du Tlelat, Fleurus, Arzew, Ain El Turck, Bou Tlelis and Saint Leu. Intensities V and VI have been attributed with a rigid interpretation of the MSK intensity scale (Medvedev *et al.*, 1981). Intensity IV has been allocated to Mostaganem, Pont du Chelif, Perregaux, Saint Lucien, Saint De-

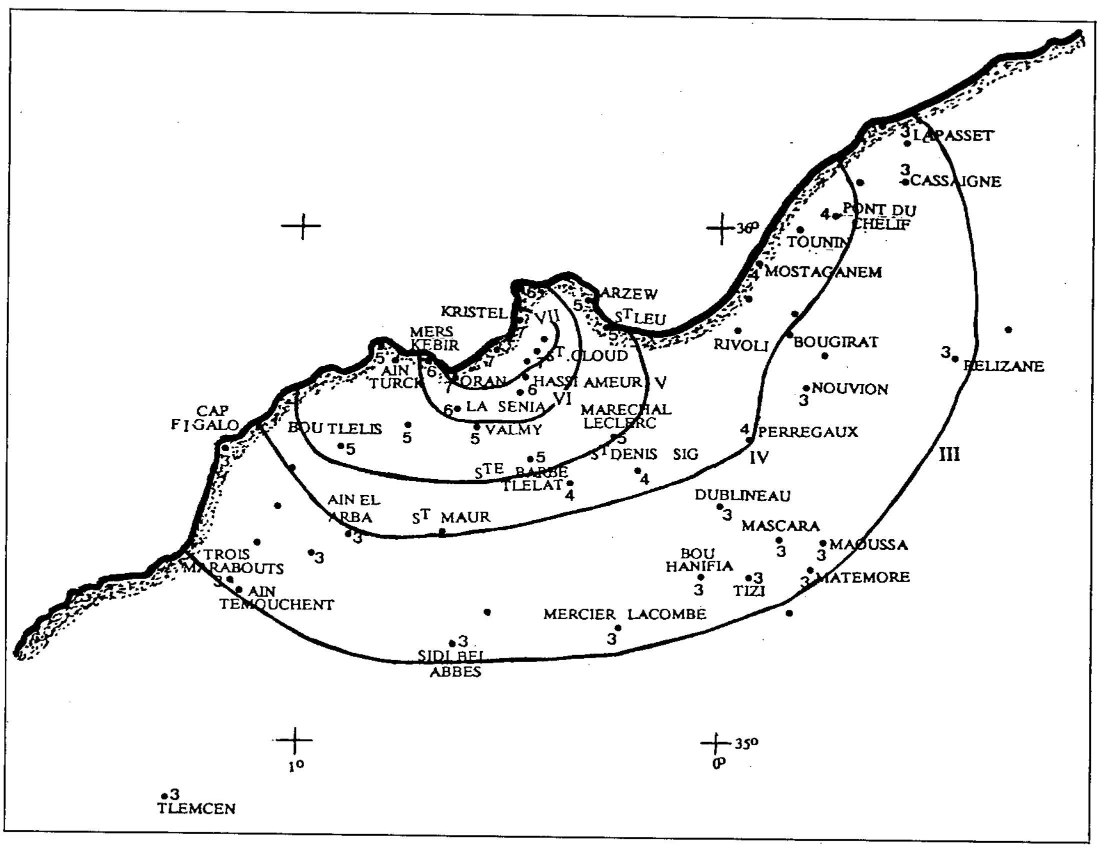

Fig. 2. Isoseismal map (in terms of MSK scale) of the main shock of the 12 December 1959 earthquake. The star shows the macroseismic epicentre of the main shock.

nis du Sig, Sidi Bakhti, Turgot and Tounin. Intensity III has been assigned to Tlemcen, Sidi Bel Abbes, Ain Temouchent, Mascara, Lapasset, Hammam Bouhadjar, Relizane, Bou Hanifia, Matemore, Trois Marabouts, Cassaigne, Sirat, Laferriere, Nouvion, Tizi, Mercier Lacombe and Maoussa. Intensities III and IV have been attributed only on felt effects and on the evidence of lack of damage to low-quality constructions.

As a result of the study of the macroseismic information, an isoseismal map of the 12 December 1959 Oran earthquake has been constructed and shown in fig. 2.

6. Magnitude determination

The surface-wave magnitude of the main shock has been evaluated from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 2 seismological stations located at distances between 15° and 22°, and a preliminary epicentre (macroseismic) at 35.75°N, 0.53°W. The data and the results are presented in Benouar (1993). The mean period is 13 s and the derived value of M_S, without station corrections, is 4.55 ($\pm$ 0.11).

7. Foreshocks and aftershocks

It apparently seems that the main shock occurred without a foreshock. In the other hand, it was followed by several aftershocks of less intensities, continuing until late January 1960.

Of the largest aftershocks, those that occurred on 12 December at 20 h 15 min and 20 h 30 min (GMT). The first one, which occurred 10 min after the main shock, was seriously felt at Hassi Ameur, Hassi Ben Okba, Hassi Bou Nif, Fleurus, Kristel, La Senia, Mers El Kebir, Mostaganem, Oran and Sidi Chami. The second one was felt in Ain El Turck, Arcole, Hassi Ben Okba, Hassi Bounif, Bellevue, Bou Hanifia, Bou Sfer, El Ancor, Fleurus, Georges Clemanceau, Kristel, Oran, Tourin and Valmy. Other less strong aftershocks, which were felt mainly in Oran and its surroundings, occurred on 12 December at 21 h, on 13 December at 0 h, 3 h, 4 h, 5 h and 8 h and on 14 December at 21 h.

The continuity of the aftershocks seriously undermined the spirits of the whole population in the region affected.

8. Discussion

According to the seismic history of the region reported by Rothé (1950, 1969), Benhallou and Roussell (1971), Mezcua and Martinez (1983) and Benhallou (1985), the region of Oran has experienced many destructive earthquakes in the past and, thus, this event is by no means an exceptional one. The main damaging events known to have struck the region occurred in 1790 (Oran) which claimed 3000 loss of lives, 1819 (Mascara), 1851 (Mascara), 1862 (Relizane), 1872 (Mostaganem), 1887 (Hillil), 1889 (Oran), 1890 (Relizane), 1912 (Arzew), 1913 (Oran), 1929 (Sig) and 1939 (Mostaganem). Since 1939, no important event has been reported in the region.

In order to re-assess the effects of this earthquake in the region with an appreciable degree of reliability, we have made a considerable investigation for contemporary documents relative to this event. The results of this show that most damage consisted of cracks in walls and ceilings in old houses. It is reported that it caused considerable alarm in the epicentral zone but there were no injuries or casualties among the population. From the macroseismic data collected, intensities have been reevaluated in many sites. Maximum intensity has been re-estimated at I_0 = VII (MSK), assigned to Oran, Saint Cloud, Kristel and their immediate vicinities, an area of about 11 km radius. The study of this earthquake is of great significance for various reasons. Firstly, it represents one of the destructive events in the Oran region. Secondly, the same epicentral area, which experienced destructive earthquakes in the past, exhibits today many humans and geographical characteristics met in other parts of the country. For these main arguments, a detailed analysis of the impact of this event in the affected region is therefore pertinent to the whole Northern Algeria, in terms of seismic hazard and risk evaluations. It provides a basic mean in the reduction of seismic risk in future disasters by suggesting new ways of improving local construction procedures, building material characteristics, strengthening and repairing existing structures, layout and implantation of new urban and rural settlements.

However, in order to study earthquakes of the past critically and to understand better the importance of the information contained in the contemporary accounts, it is imperative that the political, socio-economic and demographic conditions, cultural and religious background and building stock characteristics of the period concerned be taken seriously into account. The fact that this earthquake coincided with the Algerian Liberation War (1954-1962) which was characterized by terror, misery, unemployment and poor housing made the shock fall into a second place. The wartime was a real disadvantage in terms of human and property loss evaluations and reports. Numerous native people douars, some of them very large, sparsely distributed in the plain, which could have enhanced the data, were not mentioned in any account. We believe that the war had prevented the press and scientists to visit the affected sites in the region and thus report the whole impact of this event. It is likely that in absence of war, more attention would have been given to this earthquake and its effects amplified in the documents. It is of great interest to mention that the lack of details, particularly concerning natives and their properties, may be explained by some of neglect exercised by the French administration which was somehow screening the information. We remark that native people which constituted about 90 percent of the population in the region were not named in the reports, therefore contemporary documents should be studied with care to avoid misevaluation of the effects of the earthquake. The problem of the lack of information about the native people is discussed in section 1. Chapter I. The search for additional details, particularly in native people settlements, continues. It is of great importance that, during wartime and colonization periods in Algeria and elsewhere, macroseismic data be retrieved from contemporary military sources which, because of their official character, contain well-supplied and more reliable information.

Summarizing the results, we obtain the following final data for the 12 December 1959 Oran earthquake: origin time: 20 h 0 min 5 s (GMT); instrumental epicentre 35.72°N, 0.56°W (ISS); macroseismic epicentre 35.75°N, 0.53°W; maximum intensity I_0 = VII (MSK); magnitude M_S = 4.55 (± 0.11).

The Melouza earthquake of 21 February 1960

Abstract
This research presents one of the largest earthquakes in the Hodna region in this century. The Melouza earthquake of 21 February 1960 is one of the largest earthquakes, in terms of casualty and damage, that the Hodna region has experienced since the beginning of this century. The main shock, which lasted about 5 s, caused the loss of 47 lives, injured 129 and rendered approximately 4900 homeless (700 families); it destroyed about 600 housing units. The earthquake was felt in an area of about 20000 square km. Macroseismic data retrieved from contemporary documentary sources show that the worst affected area was the zone comprised between Melouza and Beni Ilman, where the main shock exhibited maximum intensity at I_0 = VIII (MSK). The macroseismic epicentre has been located north of Melouza, at 36.036°N, 4.175°E. The surface-wave magnitude was calculated at $M_S = 5.00$ (± 0.27). Although the damage and casualties were reported as due to the main shock, the possibility of cumulative damage remains from the heavy rain and aftershocks. According to the different sources available, the main shock was not preceded by any foreshock or any other premonitory sign. On the other hand, the earthquake was followed by a long sequence of aftershocks. The 1960 Melouza earthquake triggered major landslides and rockfalls. The total cost of damage, as estimated at that time, was about 500 million French Francs.

1. Introduction

The Melouza earthquake of 21 February 1960 occurred in the Djebel Choukchott, which is one of the secondary chain of the Tell Atlas, lying between the Hodna and the Titteri ranges. In terms of the seismic history of the region, we found no information about any serious earthquake that had occurred in the past in this particular area of the plain. However, this region, for seismotectonic reasons, should be taken as seismic, as is the whole of the Tell Atlas. Moreover, it is known that the coastal ranges, the mountains of the interior Tell and the Sahara Atlas are by turn and periodically sites of earthquakes of varying magnitudes.

The reconstruction of the macroseismic field of this earthquake is, for various reasons, of great interest. Firstly, according to the sources available to us, it represents the sole destructive earthquake to occur and to be studied in the Melouza zone for the last two hundred years. Secondly, the epicentral area of the Melouza earthquake today displays many of the geographical and human characteristics found in other seismic zones in Algeria, and therefore a careful analysis of the effects of this event is pertinent to the whole Algeria in terms of seismic hazard and risk evaluation.

The Melouza earthquake occurred at 8 h 13 min on 21 February 1960 in the western part of the Hodna region (fig. 1). It caused heavy damage to Melouza, Beni Ilman and their surroundings. According to the macroseismic data collected in this work,

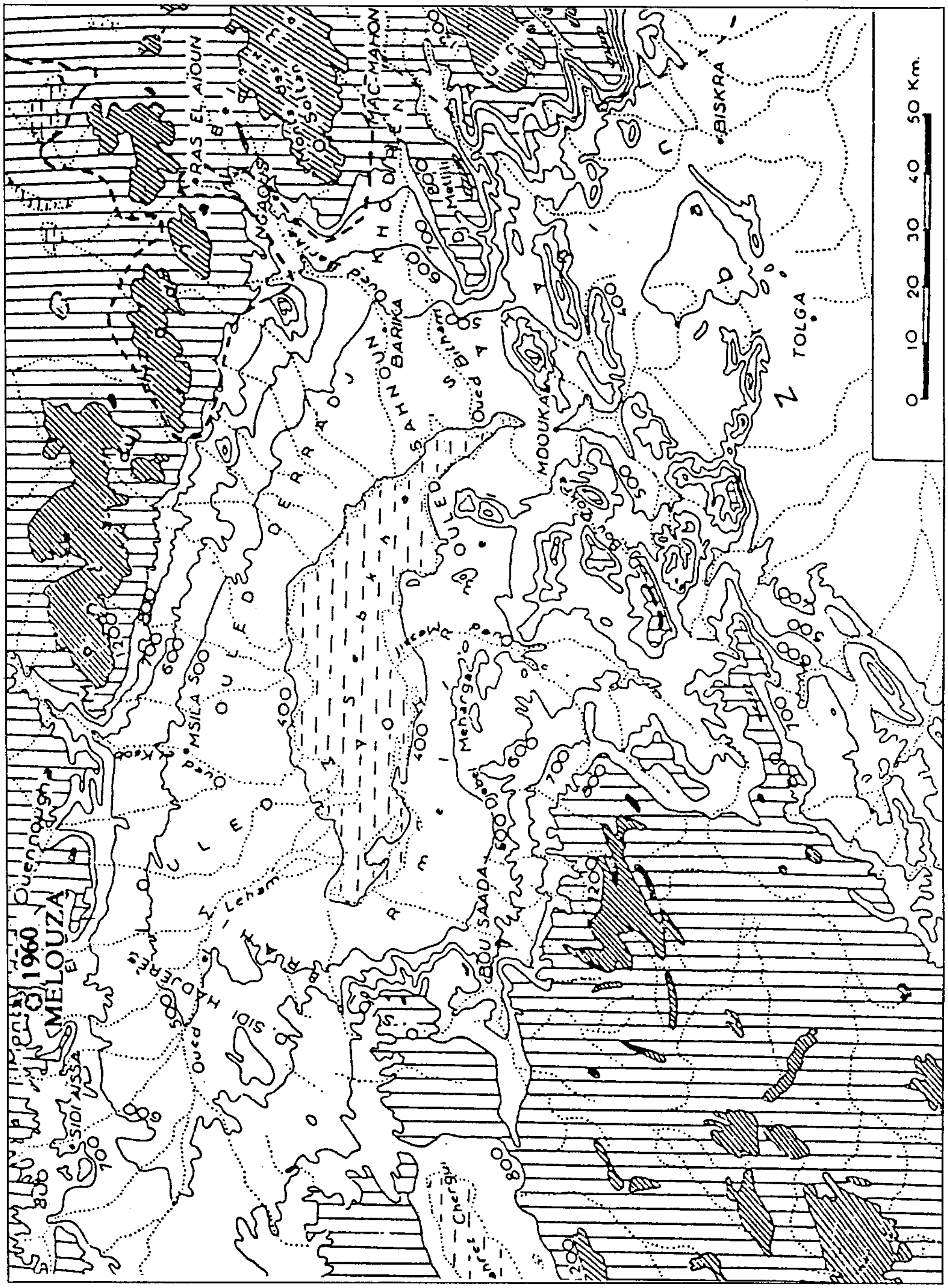

Fig. 1. Map showing the Hodna plain and its surrounding mountains. The star shows the macroseismic epicentre of the main shock of the 21 February 1960 earthquake.

the epicentre has been relocated between Melouza and Beni Ilman. Maximum intensity reached is re-evaluated at I_0 = VIII (MSK) and covers an area about 12 km radius. The earthquake was felt in a relatively small area of about 20000 square km, as far as Alger, M'sila, Bordj Bou Arreridj, Bouira, Dra El Mizan and El Adjiba. The surface-wave magnitude of this event is calculated, using the Prague formula, at 5.00 (± 0.27). The main shock, which lasted about 5 s, caused the loss of 47 lives and injured 129 people, most of them women and children; it destroyed about 600 housing units, rendering approximately 4900 homeless. The earthquake had produced severe landslides and rockfalls in the region, particularly to the north of Melouza, where large fissures were reported. Significant to slight damage was observed in an area of about 40 km radius around Melouza.

For a better re-evaluation of the strength of the shaking, an extensive investigation of source documentaries was carried out, to discover what type of buildings existed and what state they were in, and to add the macroseismic information collected and thus to re-assess intensities with a degree of reliability. The widespread destruction of the houses (gourbis) was the result of the poor quality of the constructions (adobe, drystone, heavy thatched or tile roof), their low resistance to earthquakes and their degree of deterioration. Many houses, particularly at that time (during the Algerian Liberation War 1954-1962), suffered considerable dilapidation through war, earthquakes and rain, but mainly through neglect and lack of proper repair, due to the unstable situation prevailing at that time. According to the history of Algeria, this traditional type of construction (see details of construction in Chapter II) had always shown a high vulnerability to earthquakes and heavy rain.

It is important for the macroseismic field reconstruction to mention that the region of Melouza was hit by a strong snowstorm in January 1960 which very much weakened the adobe houses.

2. Sources of information

The 1960 Melouza earthquake is one of the most important seismic events in Eastern Algeria, not only because of the casualties and the damage caused, but also because of the site of its occurrence which, according to our knowledge, had experienced no earthquakes, at least for the last two hundred years.

Despite its significance, however, it is surprising to find out that no complete scientific work was carried out Rothé (1960, 1962, 1969), summarized briefly the main casualty rate and damage, without quoting his sources. Benhallou (1985) briefly, using Rothé as his source, summarized the event in a few lines and published an isoseismal map (fig. 2). It was thought that the documentation on this earthquake would be abundant, particularly in the press as it was for past earthquakes in the region. Unfortunately, this was not so; the information was very limited. This lack of information was clearly due to the military situation of the region (war). Reports in the Algerian and International press (1960) were our main source of information. The most extensive account is given by the «Journal d'Alger», which describes the damage in detail, as well as the climatic and political situation of the period. Many photographs taken shortly after the earthquake, published by the newspapers, show the extent of damage caused, particularly to the traditional houses. Only a few writers have assigned epicentral intensity to this event at VIII (MS) by Grandjean (1960), IX (MSK) by Mezcua and Martinez (1983) and VIII (MM) by Benhallou (1985). Some agencies have also attributed maximum intensity at IX (MM), (IMPGA); IX (MM), (MOS), IX (MSK), (SSIS) and VIII-IX (MM), (BCIS). Epicentral locations were given at 35.870°N, 4.170°E (ISS); 36.00°N, 4.50°E (USCGS); 36.00°N, 4.10°E (BCIS); 35.652°N, 4.250°E (SSIS) and 36.00°N, 4.50°E (MOS). Magnitudes were also calculated at 5.90 (Lwiro); 5.75 (Pasadena and Matsushiro); 5.60 (Benhallou and Roussel,

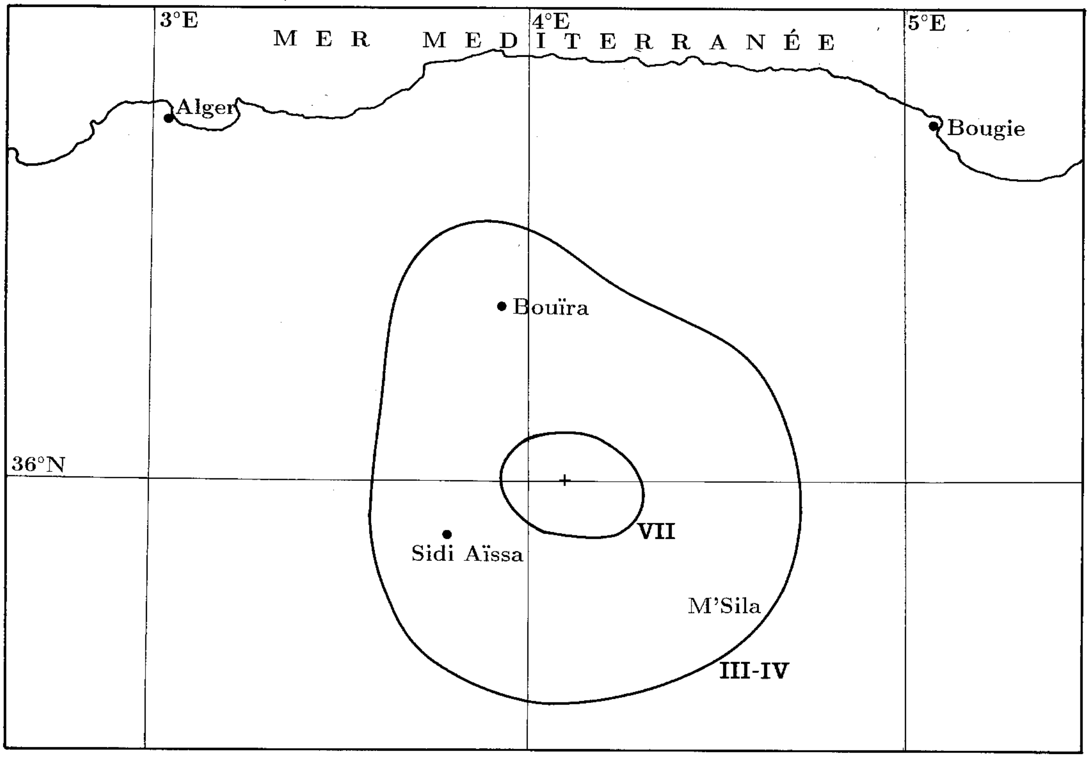

Fig. 2. Isoseismal map (MM scale) of the main shock of the 21 February 1960 earthquake, after Benhallou (1985). *Redrawn.*

1971); 5.5 (Grandjean, 1960); 5.1 (Pruhonice); 5.00 (Collmberg); 4.75-5.00 (Moscou); 5.5 (SSIS); 4.6 (Praha) and m_b = 5.6 (Kew) and 5.5 (Mezcua and Martinez, 1983).

3. Geographical aspects of the region

The Hodna plains, with the Sebkha and the Rmel, form, in the centre of Algeria, a wide closed basin surrounded by mountain ranges which, to the north and northeast, culminate at between 1200 and 2000 m (fig. 1.) Isolated from the coast by 100 to 150 km of mountain ranges, the Hodna plains are dry and hot, which make them very close to the desert climate. Geographically, the Hodna is an integral part of the high plateaux which from the west to the east, succeed each other. This plain is not only a vast topographical depression, but an important tectonic basin, which subsides to the east of the meridian of Bou Saada. An old trench of subsidence, of which the depth was recently revealed by gravimetric measures by Lagrula (1949), the arc of a circle which form the ranges of the Aures, the Belezma, the Hodna and the Ouennougha, constitute a clear geographical limit. The evolution of housing and the historical seismicity of the Hodna region are presented in the 1 January, 1965 M'sila earthquake report in this volume.

4. Damage and casualty distributions

All the information collected, from different sources available to us, were used in the re-assessment of the damage and the re-estimation of the intensity. With this aim, a comprehensive search for documents relative to this earthquake was carried out in libraries and archives in both Algeria and England. All sources give evidence of the total destruction of Melouza and Beni Ilman and their immediate vicinities. The earthquake, as reported, caused the loss of 47 lives and injured 129 of which 21 were seriously hurt. The director of construction in the region reported that 600 housing units were destroyed, rendering about 4900 people homeless (Archives of the General Government, Alger, 1960). Significant to slight damage was reported in an area of about 40 km radius around Melouza. The earthquake was associated with major landslides and rockfalls in the surrounding mountains and a smell of sulphurous gas in the whole of the affected region. The relief of the region appeared to have been particularly disrupted by the shaking and, particularly north of Melouza, large fissures and cracks were observed.

Melouza, located at 140 km southeast of the capital Alger, is on the southern flank of Djebel Choukchott, which culminates at more than 1800 m. The douar of Melouza accommodated, at that time, about 6000 mainly inhabitants living in adobe or drystones houses with heavy thatched or tile roofs, loaded with rocks the better to resist the winds. This douar is only at 60 km from M'sila, but off a dangerous, hilly country road, which did not help during the relief operations. The pilot of an army «Banana helicopter», who was flying over the epicentral region at 2000 m when the earthquake struck Melouza and its surroundings, is reported as saying: «I felt four successive shakings, it was like strong vibrations which I felt distinctly at an altitude of 2000 m». French army helicopters, which had flown over the hit area, described it as a heap of earth and dust and, on the southern flank of Kef Soumar mountain, which overhangs the douar in the north, huge fissures and landslides were observed. Old people of Melouza were reported as murmuring: «Is it truly damned, this Hodna region?». The main shock caused widespread destruction of the douar of Melouza and seriously undermined the spirits of the population. Women, children and old people were seen screaming and fleeing their homes, fearing to be buried under the rubble. All the population was terrified and camped in the open, fearing further shakings. Many of the victims, taken by surprise inside their houses, were simply buried under the debris of their homes. The sky over Melouza was covered with a very dense dust rising from the destruction of the houses and from the ground itself. The earthquake caused the loss of 8 lives and injured 65 others. Houses were observed cut into two separate parts. It is reported that 70 percent of the houses of Melouza were completely destroyed, but we recorded less loss of life there than in Beni Ilman. Among the 6000 inhabitants of Melouza it is believed that 572 families (about 3600 people) were rendered homeless. Beni Ilman, which is located at about 5 km south of Djebel Choukchott, was shocked and overcome by terror. A witness at this douar reported: «... I thought that the mountain exploded, we heard a huge explosion in the mountain and then everything was shaking, including the mountain and the ravine. I thought that it was the end of the world...». Another witness said: «... A few seconds before the shaking, my horse had broken his tether and fled to the countryside...». Many people saw a red ball passing over the mountains and some inhabitants had seen a «white smoke» coming out of the mountain. In fact, this was the landslides and rockfalls, caused by the shaking up on the mountain, which produced a very thick cloud of dust. The population was terrified as the women, children and old people screamed and rushed out, fleeing from their collapsing houses to the open fields. The centre of this douar, as described by the local press, looked as if it was devastated by heavy bombing. The earthquake caused the loss of 39 lives, injured 64 and made 1300 homeless; it completely destroyed about 50 percent of the buildings of this douar. After the earthquake, everybody in the douar was obliged to sleep under the army tents and eat canned food. In the Mosque of Mechta-Casbah, which was used as a school for Koran teaching, 15 children were buried under the debris and 9 of them were subsequently found dead. The newly built army post (SAS: Security and Administrative Service) was reduced to ruins. The toll of the injured, reported to be 64, of which 21 were seriously hurt, was not communicated in detail. It is of interest to mention that a violent snowstorm had already destroyed a school and caused various damage to Beni Ilman in January 1960. The douars of Mousquek and Makmen, located between Melouza and Beni Ilman, experienced significant damage. Some of the houses were completely destroyed while others showed serious cracks, but no casualties were reported. Bordj Khris, 20 km west of Melouza, experienced the collapse and serious damage of some housing units. At Sidi Aissa and Ain El Hadjel, about 40 km southwest of Melouza, the houses sustained such slight damage as cracks in walls and the fall of ceilings. 45 km northwest of Melouza the colonial village of Aumale was slightly hit, only small cracks were reported in some houses or gourbis. The earthquake was strongly felt east of Melouza, at the junction of the Hodna and the Bibans mountain ranges, south of Portes de Fer.

The main shock was reported to have been felt at Alger, Bouira, Medjana, Dra El Mizan, El Adjiba, but we found no evidence that it had been felt beyond these places.

5. Intensity distribution

The reconstruction of the macroseismic data field of this event has been carried out in using various contemporary documents related to the earthquake period. The intensity of the shaking was re-estimated, after much analysis of the data, with reference to the Medvedev-Sponheuer-Karnik – MSK – scale (1981).

The constructions of the region, at the time of the earthquake, were adobe or drystone houses with heavy thatched roofs (described for the whole Hodna region in this volume – M'sila 1965 earthquake case study –). This widespread type of construction (type A as defined by the MSK scale) had shown in the past, in many parts of Algeria, a very low strength and high vulnerability to earthquakes and even to rain, and therefore the degree of damage caused to these dwellings is an indication of the weakness of the structure rather than the strength of the ground shaking. As a conclusion, at intensity IX-X (MSK), most of the houses would be totally destroyed and any douar would thus look equally, but no more, devastated at higher intensities. For this reason and according to the macroseismic data collected, it is unlikely that intensity IX was reached.

After an analysis of the different factors that may have contributed to the destruction of these douars, maximum intensity was re-estimated at VIII and was allocated to the area comprised between Melouza and Beni Ilman. Intensity VII was assigned to Bordj Khris. Intensities V-VI were allocated to El Hadjel, Aumale, Mansoura and Sidi Aissa. Intensities III-IV were allocated to Alger, Bouira, Medjana, Dra El Mizan and El Adjiba according to felt reports (Press, 1960).

As a result of the analysis of the macroseismic data, an isoseismal map of the 21 February 1960 Melouza earthquake is drawn and shown in fig. 3.

6. Magnitude determination

Surface-wave amplitudes and periods of the main shock were reported from 9 seismological stations at epicentral distances between 6° and 22°. The surface-wave mag-

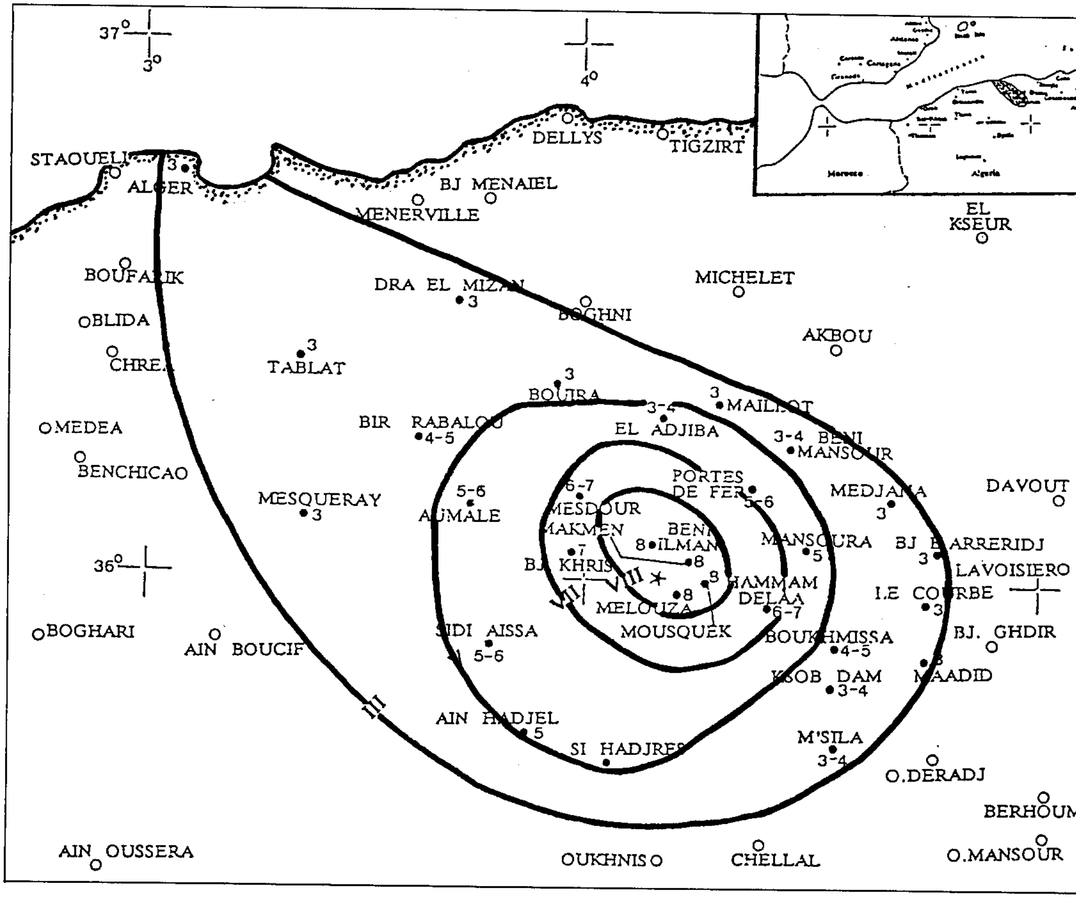

Fig. 3. Isoseismal map (MSK scale) of the main shock of the 21 February 1960 earthquake. The star shows the macroseismic epicentre of the main shock.

nitude of the earthquake is calculated from the standard Prague formula (Vanek *et al.*, 1962) using teleseismic amplitude and period readings and a macroseismic epicentre at 36.036°N, 4.175°E. The data and the results are given in Benouar (1993). The mean period is 13 s and the derived value of M_S, without station corrections, is 5.00 ($\pm$ 0.27).

7. Foreshocks and aftershocks

No foreshock was felt, according to the seismological stations records of the region (Alger, Setif and Relizane) and to the population of the affected zone. Other phenomena, such as the behaviour of animals, could have been premonitory.

On the other hand, the main shock was followed by a long sequence of aftershocks of much less intensity, continuing until 25 February. There were 3 early aftershocks at 9 h 15 min, 10 h 30 min and 12 h 30 min. The first one accentuated the damage of the houses which had been seriously affected by the main shock (8 h 13 min) but the second and the third completed the destruction (Press, 1960). These aftershocks created a sensation of insecurity which seriously undermined the spirits of the population for several days.

8. Discussion

In terms of the seismic history of the region, according to Chesneau (1892) and Rothé (1950), we found no information about any destructive earthquake having occurred, in the last two hundred years, in this particular region of the Hodna. However, this region, for seismotectonic reasons, should be taken as seismic, as is the whole Tell Atlas. This moderate event occurred on the south flank of Djebel Choukchott which constitutes one of the meridional mountain chain of the Tell Atlas, situated between the Hodna and the Titteri ranges. The press (1960) reported that the main shock caused the loss of 47 lives and injured 88 of which 21 were seriously hurt, and Benhallou (1985), without quoting his source, states that 47 lives were lost and 129 injured. Most of the victims were old people, children and women, as the men were already at work in the fields. The number of victims is certainly higher than was officially reported. Many people, surprised by the shaking, were buried under the rubble of their houses in scattered douars, which did not receive any relief. We believe that the exact toll of casualties may never be known, as many of the victims were immediately buried to conform to the Islamic law and never reported to, or neglected by, the French authorities (SAS). The whole affected area, shortly after the earthquake, was declared disaster zone and thus fell under the full authority of the army, imposing censorship. Some press reports mentioned 308 victims at Beni Ilman but we could not find any other source to confirm this. The 1960 earthquake occurred at the height of the war (1954-1962) which was much more active in Eastern Algeria; as three years earlier, on the night of 27 to 28 May 1957, 316 native men, suspected of helping the enemy, were put to death at Melouza and Beni Ilman by the liberation army. The war situation prevented the press and even the French army from visiting isolated douars in the surrounding valleys and mountains. The French administration was in total control only of important douars, which may explain why the information reported was limited to large douars and surrounding towns. The fact that this earthquake coincided with the war period was a real disadvantage in terms of casualty and damage reports; many douars, sparsely distributed in valleys and on the flanks of the surrounding mountains, which could have enriched the data, were not mentioned in any contemporary documents.

Macroseismic data collected, mainly from Algerian newspapers, confirm that the worst affected area lies between Melouza and Beni Ilman. According to MSK scale, the main shock exhibited a maximum intensity in the range of VIII-IX within an area of 12 km radius. On first analysis, we were tempted to assign an intensity IX but, having carefully considered the characteristics of the building stock in the region, we were convinced that the extensive damage was much more the result of the poor quality of the constructions rather than the severity of ground shaking. After a critical analysis of the data collected, maximum intensity I_0 = VIII (MSK) was assigned to the area comprised between Melouza and Beni Ilman. This intensity is relatively lower than some allocated by other writers and agencies. Although most damage was reported as due to the main shock, the possibility of cumulative damage remains from early aftershocks and rain.

Although this macroseismic reconstruction is a preliminary one, it constitutes an important advance in knowledge of many important factors in the event. From our results, it appears that the earthquake was a shallow one with moderate magnitude. This is shown by: 1) the heavily destroyed area, which exhibited intensity VIII, was limited to a small area (Melouza and Beni

Ilman) about 12 km radius; 2) the relatively small area over which the shock was felt, about 20000 square km.

In similar situations, lack of critical analysis of civilian and military historical sources will definitely lead to gross misjudgment of the effects of the earthquake.

Summarizing the results, we obtain the following final data for the 21 February 1960 earthquake: origin time 8 h 13 min (GMT); macroseismic epicentre at 36.036°N, 4.175°E; focal depth about 8 km; maximum intensity I_0 = VIII (MSK); magnitude M_S = 5.00 (± 0.27).

The Agadir earthquake of 29 February 1960

Abstract
This research examines the largest recorded and felt seismic event in Morocco during these last two centuries. An earthquake of proportions never felt before in Morocco struck the city of Agadir on Monday 29 February 1960 (third night of Ramadhan), at 23 h 41 min (GMT). The city of Agadir, an Atlantic coastal town and harbour, which accommodated about 33000 inhabitants at the time of the earthquake, is located at 616 km southwest of the capital Rabat. The main shock, which lasted about 15 s, caused the loss of about 12000 lives, injuring at least 12000 others and trapped thousands of survivors under the rubble of the structures; it destroyed completely about three fourth of the constructions and damaged numerous beyond repair. Collection and analysis of the macroseismic data relative to this event have led to a detailed re-evaluation of intensities in several sites. Maximum intensity has been re-estimated at I_0 = X (MSK), allocated to major districts of Agadir, an area of about 10 km. The shock affected structures, with intensity V^+ (MSK), in the zone comprised between Ounarha, Es-Saouira, Imi N'Tanout, Taroudannt, Ait Baha and the coast. Radius of perceptibility was fairly large, the shock was intensely felt up to Tiznit in the south and Bou Azzer in the east. In the southeast, it was recorded in Bou Isakarne (150 km away), but was not felt in Foum El Hassane (180 km). On the other hand, it was perceived at Ourzazate, 400 km distant. North of the Atlas, it was clearly felt up to Casablanca. From the intensity data, an isoseismal map has been constructed and a macroseismic epicentre located at Agadir, at 30.52°N, 9.52°W. The earthquake was preceded by two foreshocks and followed by a long sequence of aftershocks. The main shock was recorded by most of the seismological stations in the world, up to Byrd 13700 km away. The instrumental epicentre was located at 30.57°N, 9.43°W by ISS (1960). The surface-wave magnitude of the earthquake has been calculated, without station corrections, at 5.70 (± 0.23). The shaking was associated with several ground features as fissures, cracks and sand volcanoes. We found no report about any important fault or tectonic phenomenon. This earthquake caused considerable economic losses to Morocco, had large psychological impact in the whole region.

1. Introduction

The 1960 Agadir earthquake constitutes the greatest recorded and felt seismic event in Morocco. No other destructive seismic event is known to have occurred in the region since 1731, the date in which Hoff (1840), according to Verneur (a French traveller), indicated that Santa Cruz (identified with Agadir) was destroyed by an earthquake. Agadir, a city of about 33000 inhabitants, is located on the shores of the Atlantic coast at 616 km southwest of the capital Rabat (fig. 1). The earthquake occurred on the 29 February 1960 at 23 h 41 min (GMT), when the hotels were full of a gay tourist crowd and the native Moroccans were observing the third night of Ramadhan. The main shock, which lasted 15 s, caused the loss of about 12000 lives, injuring at least 12000 others, trapping most of the survivors under the rubble and

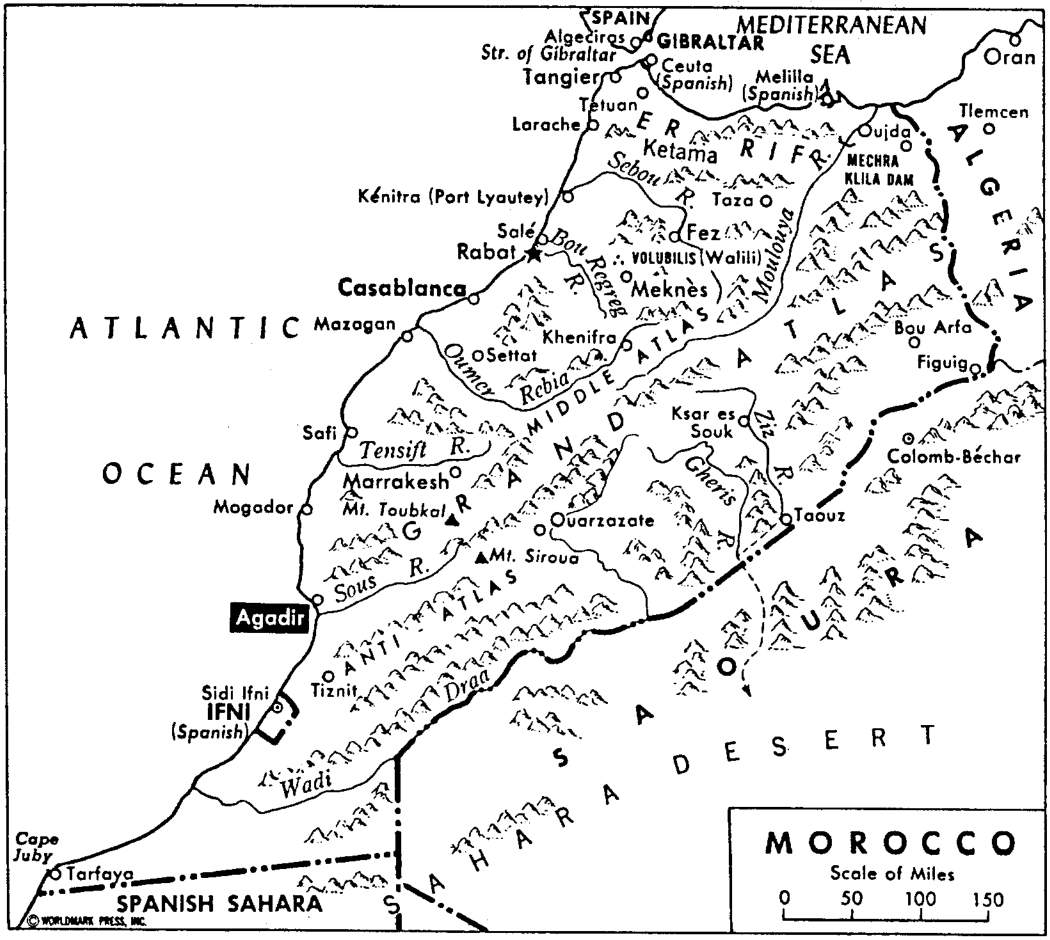

Fig. 1. Map of Morocco.

rendering most of the population homeless; it destroyed the Moroccan constructions at the rate of 100 percent and the European structures at about 70 percent. The epicentral area, within which the shock caused most destruction and casualties, accommodated about 33000 people. It, not only, destroyed the city of Agadir, but also devastated many local traditional villages situated to the north and northeast of the city.

The earthquake was preceded by two slight foreshocks and followed by a long series of aftershocks. It was associated with few landslides, fissures and cracks in the streets of Agadir and its vicinity, mainly in filled ground. Several sand volcanoes were observed in the mouth of River Souss. On the other hand, the earthquake was not linked to any major fault or tectonic features. In spite of its occurrence very near to the coast, the shaking did not provoke any roughness in the ocean. The telephone lines, the electricity and water services were interrupted.

In order to reconstruct the macroseismic field of this event, a broad investigation for contemporary documentary materials relative to this earthquake was carried out. Compilation and careful analysis of the macroseismic information collected have led to a detailed re-estimation of the amount of damage caused to man-made structures and to nature, and how it was felt by the population. As a result of this analysis, intensities have been re-evaluated anew in many sites. Maximum intensity has been re-estimated at I_0 = X (MSK), allocated to the centre districts of Agadir, an area of about 10 square km. The earthquake affected structures in the zone containing Ounarha, Es-Saouira, Imi N'Tanout, Taroundannt, Ait Baha and the coast, with intensity V^+ (MSK). Radius of perceptibility was fairly large, the shock was intensely felt up to Tiznit in the south and beyond Bou Azzer in the east. In the southeast, it was observed in Bou Isakane (150 km), but was not felt in Foum El Hassane (180 km). On the other hand, it was perceived in Ouarzazate (400 km) and clearly felt up to Casablanca.

This earthquake caused considerable economic losses to Morocco, had large psychological impact in the whole region.

2. Magnitude determination

The surface-wave magnitude of the main shock has been computed from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 14 seismological stations located at distances between 20° and 45°, and a preliminary epicentre (macroseismic) at 30.52°N, 9.52°W. The data and the results are presented in Benouar (1993). The mean period is 14 s and the derived value of M_S, without station corrections, is 5.70 (± 0.23).

3. Sources of information

To reconstruct the macroseismic field of the 1960 Agadir earthquake with a certain degree of reliability, an extensive search for documentary source materials relative to this event was made. Because of the extent of the damage and the casualty toll it caused, this earthquake has been studied in details by many scientists and well reported in the local and international press. A considerable amount of documentary materials, field reports, scientific papers, general chronicals, special studies and press reports provide invaluable information rich in details. It is not necessary to describe each work individually; their comparative qualities and shortcomings emerge from the use made of them. The most extensive reports are mentioned in what follows. Rothé (1962), whose work is based on his own field visit, published a complete report on the Agadir earthquake and the Moroccan seismicity, including an isoseismal map of the event (fig. 2). Debach (1962), head of the Service de Physique du Globe et de Météorologie (SPGM, Morocco), following his field visit, published a preliminary report on the Agadir earthquake and also an isoseismal map (fig. 3); it is important to mention that this work was done by the end of March 1960, only few weeks after the disaster. Erimesco (1960), geophysician at the Institut des Pêches Maritimes du Maroc (Fishing Institute of Morocco), from his own field visit, studied the effects of the earthquake in the harbour, the coast and the bay of Agadir. Choubert and Faure-Muret (1962), from the Service de la Carte Géologique du Maroc (Geological Map Service, Morocco), published their own field observations accompanied with an isoseismal map (fig. 4). They prepared a detailed study of the earthquake, its impact and geological interpretation, which is illustrated by 62 photographs. Figure 5 shows an isoseismal map of the main shock, after Choubert, Faure-Muret and Erimesco (1962). Another isoseismal map (fig. 6) of the main shock of the Agadir earthquake was constructed from the data presented by Ambroggi (1960), Choubert *et al.* (1962), Erimesco (1962) and Rothé (1962). Borges and Madeira Costa (1961) visited the af-

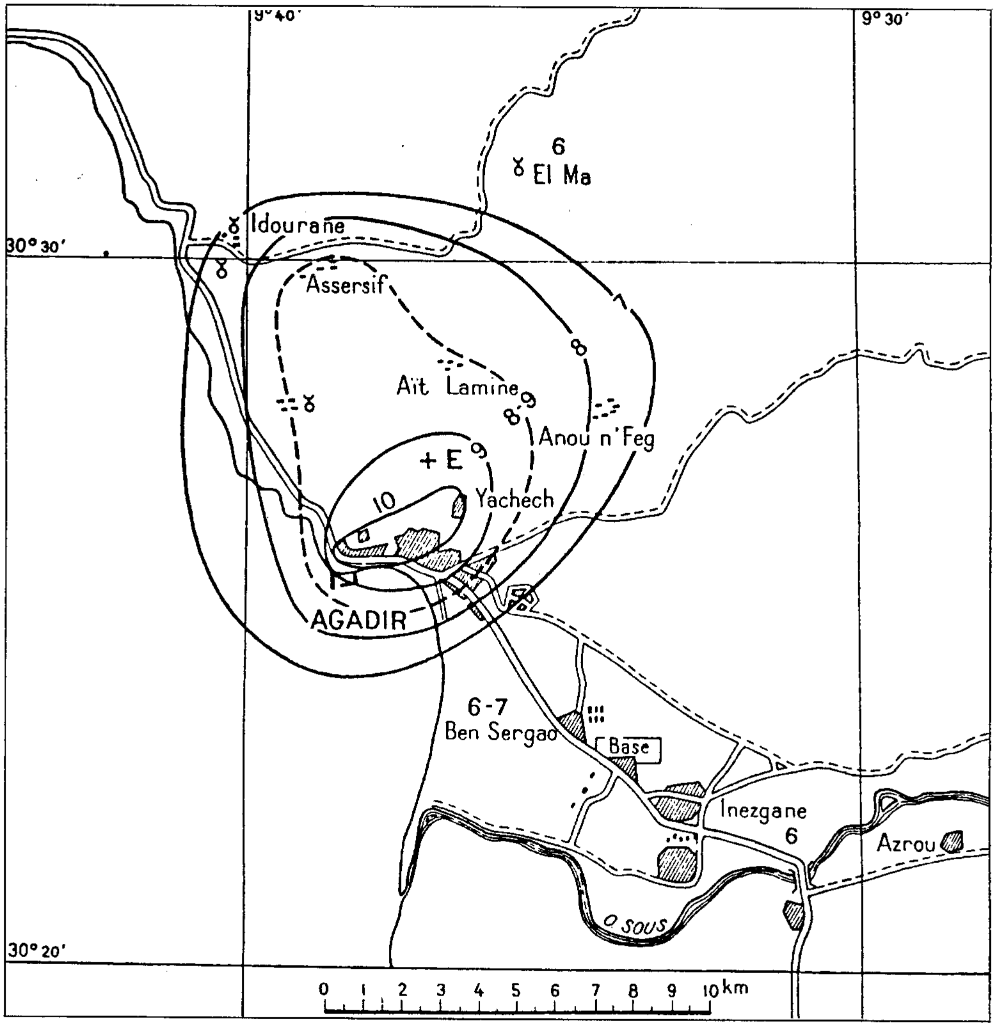

Fig. 2. Isoseismal map (in terms of MM scale) of the main shock of the 29 February 1960 Agadir earthquake, after Rothé (1962).

fected area and published a report on the behaviour of the constructions during the earthquake. This report is illustrated with more than 56 photographs. The American Iron and Steel Institute (1962), of which the information are based on a visit to the affected zone by four experts who inspected the area three weeks after the disaster, published a book on this event. This book comprises in addition to the photographs taken by the team members, a certain number of photographs of the U.S. Navy taken shortly after the main shock. The earthquake was largely reported in most news publications throughout the world. It was particularly related in the local and international press which give important detail of the extent of the damage,

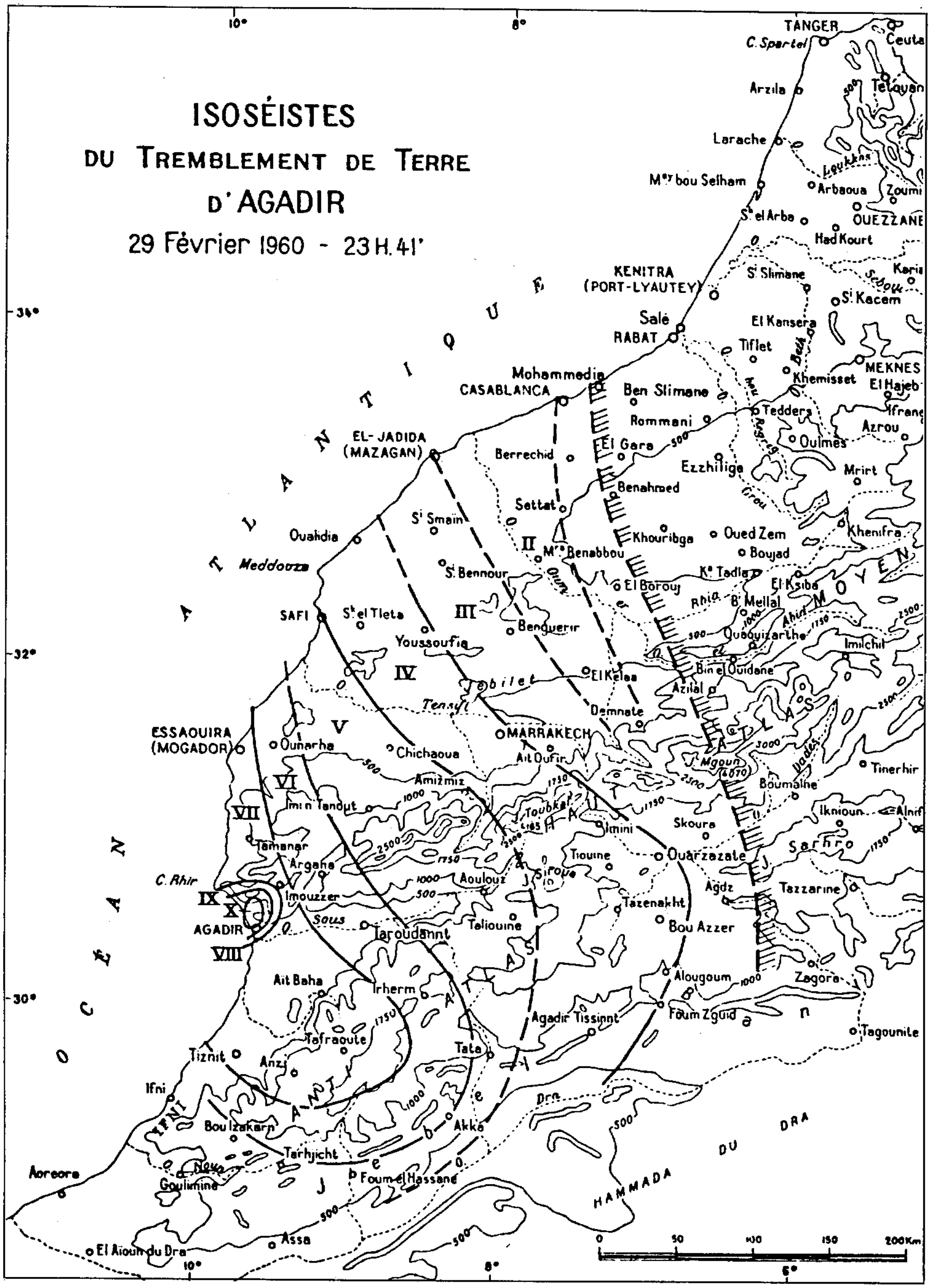

Fig. 3. Isoseismal map (in terms of MM scale) of the main shock of the 29 February Agadir earthquake, after Debrach (1962).

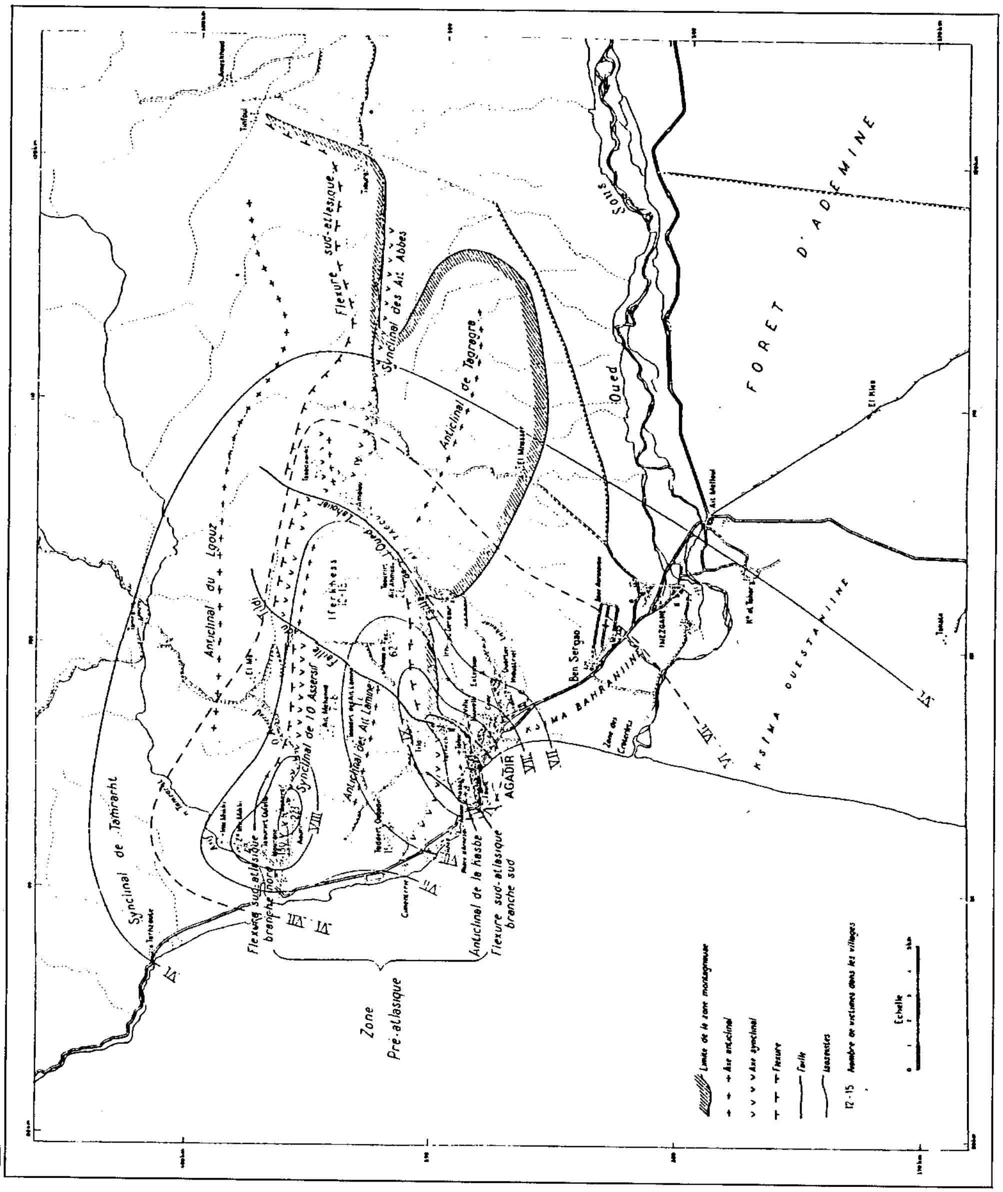

Fig. 4. Isoseismal map (in terms of MM scale) of the main shock of the 29 February 1960 Agadir earthquake, after Choubert and Faure-Muret (1962).

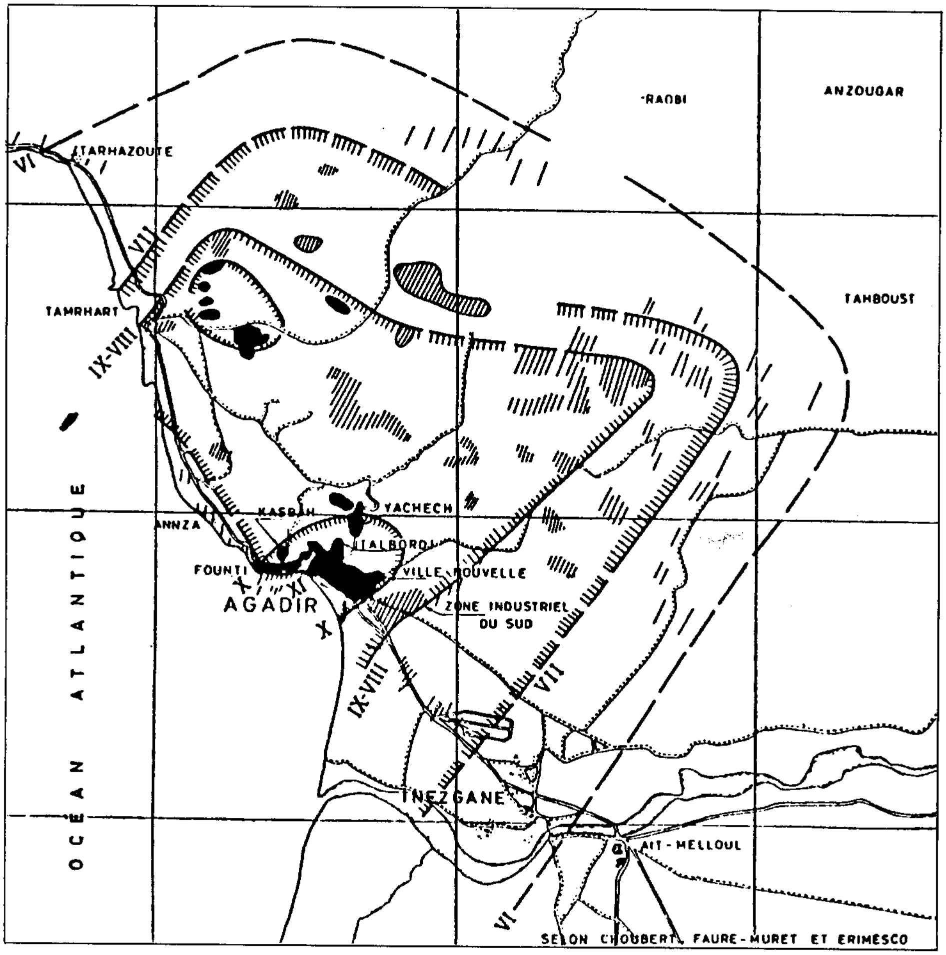

Fig. 5. Isoseismal map (in terms of MM scale) of the main shock of the 29 February 1960 Agadir earthquake, after Choubert, Faure-Muret and Erimesco (1962).

socio-economic and psychological implications; the most extensive accounts are given in «Le Monde» newspaper (1960). Among the magazines, the earthquake was reported with an abundance of photographs in «Paris Match» (1960) and «Aesculape» (1960). The drawback of all these reports is the lack of details outside the city of Agadir and its immediate vicinity. Many photographs relative to this earthquake are shown in Benouar (1993).

In the recent catalogues, the instrumental epicentre assigned to this shock is: 30.57°N, 9.43°W (ISS); 30.00°N, 9.00°W (USCGS); 30.450°N, 9.617°W (BCIS); 30.00°N, 10.00°W (MOS) and 30.50°N, 9.66°W (Despeyroux, 1960). Magnitudes are calculated at: 6.25-6.40 (PAS); 5.75 (MOS); 5.9 (Rothé, 1960); 5.7 (Ben Sari, 1987); 5.75 (Despeyroux, 1960); 5.7 (Kew); 5.75-6.0 (Strasbourg and Rome); 5.6 (Zagreb); 5.5-5.75 (Prague); 5.5 (Collemberg);

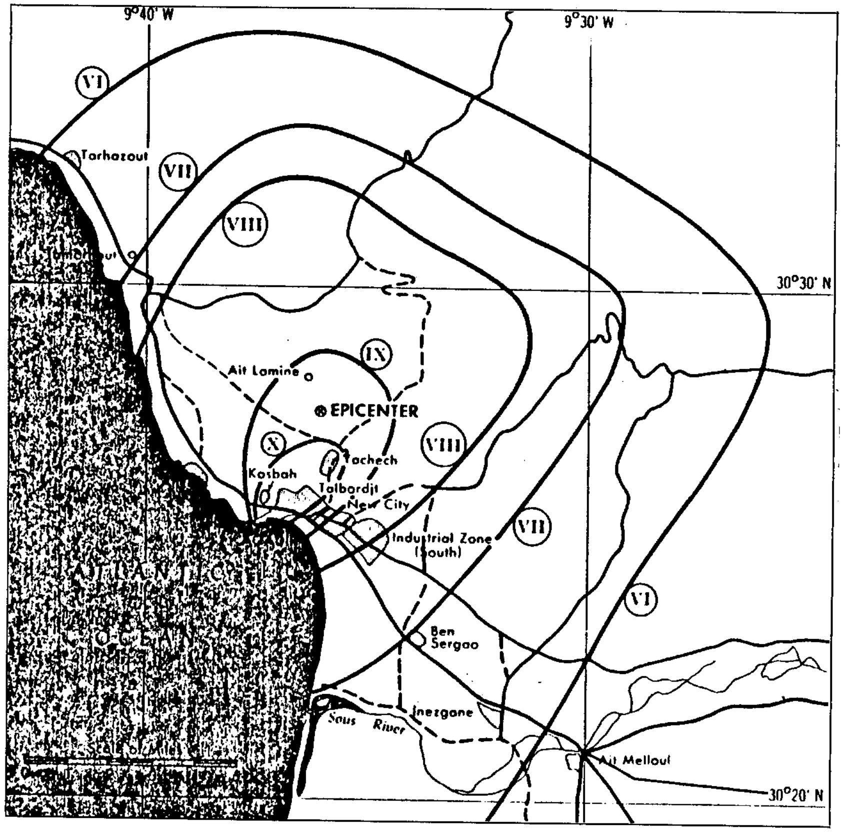

Fig. 6. Isoseismal map (in terms of MM scale) of the main shock of the 29 February 1960 Agadir earthquake, after Choubert, Faure-Muret, Erimesco and Rothé (1962).

5.4 (lvov); 6.75 (Hurbanovo); 6.25 (Quetta); 6.0 (Skalnate); 6.75-7.0 (Bratislava); 5.9 (Pruhonice); 6 (Warzawa); m_b = 6.0 (Mezcua and Martinez, 1983) and 6.1 (Kew). Maximum intensity is estimated at: X (MM), (Rothé, 1960; Despeyroux, 1960); X (MM), (Choubert and Faure-Muret, 1962) and X-XI (MM), (Debrach, 1962; Erimesco, 1962; Ben Sari, 1987).

4. Geographical and historical aspects of the region

Agadir, a city of about 33000 inhabitants, is located on the shores of the Atlantic coast at 616 km southwest of the capital Rabat. Agadir, or Agadir i n'rir (in Berber), which means «fortress on the ridge», is spread out for 5 km along the edge of the beautiful bay. The city, by its geographical position, has become famous as a tourist resort. It has been also playing an important role in the Moroccan economy as an industrial zone and a shipping port.

Ambroggi (1960) has studied in details the geological structures of the Agadir region and its close vicinity of which a brief description of the local structure is presented in what follows. The city lies just south of the axis of the high Atlas ranges.

In this zone, the so-called pre-Atlas area forms a sharp limit between the Atlas mountains and the plains of the River Souss. The whole zone tends almost in the east-west direction and contains two branches of folding separated by a syncline. The southern branch which crosses the Kasbah district is tightly folded while the northern branch, which makes the hinterland of Agadir, is rather gently folded, its cretaceous beds approaching a near vertical position. The city was built on the spurs of the high Atlas except for the Nouvelle Ville (New City), the industrial zone and part of the Front-De-Mer which are located on quaternary and recent unconsolidated sediments. A number of major faults were visible in the area, one of which follows the River Tamghart, about 10 km north of Agadir, running in east-west direction. There are three faults which cross the structural folding of the Kasbah ridge; the Kasbah, the Tildi faults and the Lahouar fault which passes just south of Agadir.

The history of Agadir has been recorded since ancient times when it was called Portus Risadir (Julien, 1970). It is known that in 1505 a Portuguese established a fishing village at the site and named it Santa Cruz de Aguer. Not able to defend it from the increasing pressure of the Moroccans, he sold it in 1513 to King Manuel of Portugal who converted it into a fortified city. The site was well protected until Moulay Mohammed had built the Kasbah, in 1540, on the crest of a hill overlooking Santa Cruz. After heavy bombardment by the Moroccans, the city capitulated. Since then, the city has been an important fishing and shipping centre until the middle of the 18th century when its port was closed. The reasons for its decline are not really known.

However, according to seismic history of Morocco, the city was reported completely destroyed in 1731 by a strong earthquake which could be the cause (Hoff, 1840). It began to recover and assume again its major role in the Moroccan economy since the early 20th century. The population increased from 6000 inhabitants in 1906 to 33000 in 1960. Most of the development of the city occurred in the post-war period. At the time of the earthquake, Agadir was a combination of very modern European buildings and very old local traditional dwellings. The city was divided in districts (fig. 7) as follows: 1) the Kasbah, built in 1540; 2) Founti, which is believed to be the original place of the Portuguese village of Santa Cruz, is located in the port zone at the foot of the hill on which is built the Kasbah; 3) Talborjt is the area where the town expanded in 1932; 4) Yachech is a poor Moroccan suburb located on the slopes of the Tildi ravine in northeast of Talborjt; 5) Administrative Plateau is located in the south of Talborjt, it contains newly built residences and public buildings; 6) Nouvelle Ville (New City) was built after 1945, it contains modern European type office buildings and flats, and is separated from the Administrative Plateau by the Tildi ravine; 7) Front-De-Mer is a narrow zone about 1600 m long and 150 m wide along the Boulevard between the beach and Talborjt and, Administrative Plateau and Nouvelle Ville. This zone is well known for its modern, tall office buildings, flat and hotel structures; 8) Industrial zone (north), which comprises Anza and Arhesdis, is mainly a sector of fish canneries, but also containing a cement plant, flour mills and electric power stations; 9) the port is located west of Founti and where the constructions consist mainly of steel frame warehouses.

5. Building stock characteristics

The distribution and the characteristics of the building stock in Agadir and its close surroundings are widely related to the historical development of the region. The structures can be divided with respect to the different historical periods and development trends to the following three categories: a) traditional local constructions built before the French colonization; b) those built during the colonization and up

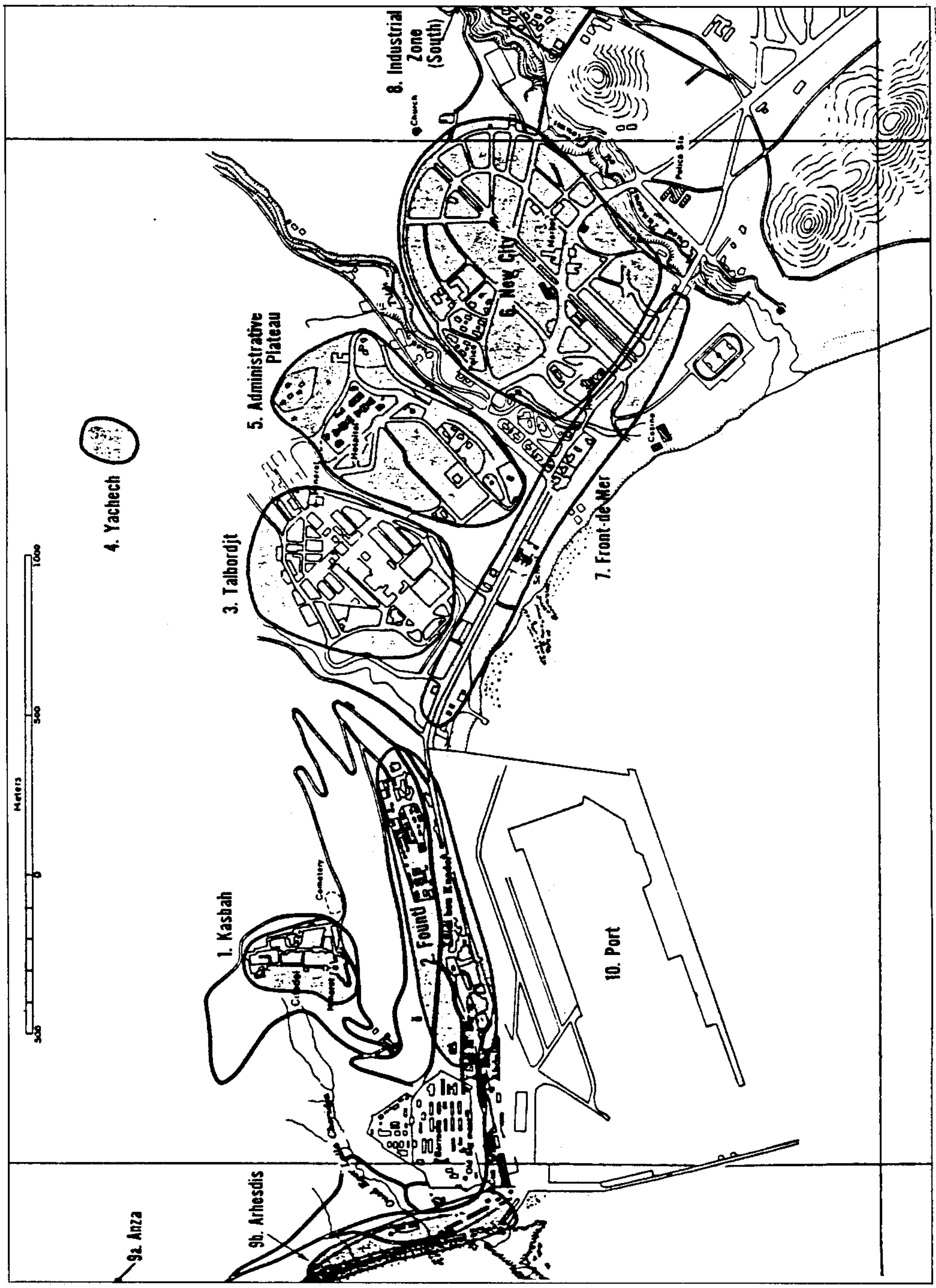

Fig. 7. Map of the main districts of the city of Agadir.

to 1940 and c) modern reinforced concrete European building types, built after 1945.

As most of the old towns in North Africa, Agadir had also its original nucleus built in the 16th century which is known as the Kasbah. The constructions in this site consist mainly of adobe and stone masonry bearing wall structures. In these dwellings, the mortar joints were thick, and made of mud and sand; roofs varied from timber rafters covered with corrugated sheet iron to reinforced concrete slabs. This type of structure was prevailing also in the quarters of Founti and Yachech. The structures in Talborjt and in the newer districts consisted mainly of three to four stories in height, and frequently had a smooth plaster finish, giving them the appearance of modern European buildings. These structures were generally unreinforced masonry bearing walls and partitions supporting heavy concrete slab floors and roof. The masonry was either stone or clay tiles; the mortar joints were thick and varied from sandy clay to good quality sand and cement. The third type of predominant structures is reinforced concrete buildings. Some of them had reinforced concrete beams and columns which were designed for only vertical loads; the remaining consisted of rigidly joined beams and columns and for these both cases, walls and partitions were of ordinary masonry.

The building stock in Agadir, as elsewhere in North Africa, has several variable characteristics such age, materials and structural systems. The constructions exposed to the earthquake consisted mainly of structure of types A, B and a small percentage of type C as defined in the MSK intensity scale.

6. Damage and casualty distributions

The abundance of information relative to this earthquake, available in numerous sources, describe in details the effects of the shaking on humans, man-made structures and on the ground itself. The ground deformations (landslides, fissures, cracks and liquefaction) were not really significant. No significant tectonic feature was observed in the whole affected zone (Choubert and Faure-Muret, 1960). The immediate consequences of the earthquake are measured in terms of casualties among the population and extent of the damage. Most of the contemporary documents give evidence on the total destruction of major quarters of Agadir. The epicentral area, within which most casualties and damage were recorded, accommodated at least 33000 inhabitants. The main shock, which lasted 15 s, killed an estimated number of 12000 people, injuring at least 12000 others and making the remaining homeless; it destroyed about 75 percent of the building stock of Agadir and its close vicinity.

In the city of Agadir, several streets were presenting local fissures which occurred mainly in places where the roads are built on filled ground. This consists of longitudinal cracks which cross the asphalt and the filled ground alike. The transversal fissures were rare and not important; they did not prevent the road traffic. Generally, the fissures were not accompanied by any throw, except that sometimes they showed, however, small ones not exceeding 10 cm. The surface ruptures in this zone were significant because they were aligned along a WSE-ENE line which superposes the south Atlas tectonic accident. In the district of the Kasbah and on the flank of the hill, very important longitudinal fissures were observed. In the ramp, filled ground, towards the hotel Mauritania, numerous significant longitudinal cracks were observed, but almost without any throw. On the border of the Tildi Valley, on the ramp, small throw fissures were experienced by the natural slope. The road heading to Talborjt (built on filled ground) was seriously cracked near the crossroads of La Somme and Taroudant streets. Along the harbour and in the ramp of Es-Saouira, several oblique fissures were observed on the route, with throws of about 5 to 8 cm towards the south. Very near the largest pier, major surface fissures were observed which caused significant damage to the port facilities and its equipment. Furthermore, the parapet of the route as well as the water pipes were cut off. These same surface ruptures were found in the quarter of Founti, with a throw of about 30 cm in the street which also is built on filled ground. Close to the «Immeuble Consulaire» building, in the crossroads (Place Bourguignon), only small transversal cracks, without any throw, were reported. On the other hand, the Boulevard heading to Talborjt, east of the hotel Mauritania (Boulevard Moulay Youssef), was not fissured; it is of interest to mention that this Boulevard is built in a trench, unlike many others on filled ground. Numerous surface ruptures were observed in the surroundings of Agadir. The most apparent fissures were reported on the road that follows the ravine in the northern part of the Kasbah. Other cracks were seen in Anou N'Feg to the east of Agadir. It is of interest to mention that wherever the roads cross gorges or calcareous cliffs, landslides and rockfalls were reported. Landslides of light soils are frequent, particularly along the roads in trenches. The liquefaction phenomenon was reported by Erimesco (1962) during his field visit in the Souss, described by Ambroggi (1960) and Rothé (1962) and related in the press (1960). This consists of sand volcanoes observed in the zone of the dune near the mouth of the River Souss. Very near the liquified zone, a ground surface fissure of several tens of metres long, about 30 cm wide and a throw of 20 cm was reported. As a hydrological effect, the flow of a spring in the region of Tabadkoukt (northeast of Agadir) increased considerably. A detailed study of the impact of the earthquake on the soil was published by Choubert and Faure-Muret (1962).

As earthquakes of this size, the Agadir earthquake was accompanied by a frightful, terrifying and deafening underground rumbling compared by some people to that due to the passing of a flight of a hundred jet aircrafts above them and by other to strong thunder or explosions. In the city itself, the noise accompanied the main shock. Along the Atlas in the region of Argana, it seems that the rumbling preceded the shock; inhabitants were awaken by the noise and not by the shaking which they felt afterwards. In the other hand, in Souss area, it appears that the phenomenon was reversed. At Ait Melloul, located at about 15 km of Agadir, the rumbling was heard after the main shock. The rumbling was clearly perceived in a zone of more than 50 km radius (Rothé, 1962).

Several optical phenomena were also reported by many witnesses in the Agadir region. Many accounts mention a fireball that came from the ocean to a small distance from the coast. The most interesting testimony is that of the crew of the trawler «Rollando». The members of the crew reported they had the impression that a strange gleam, «fireball», had appeared between the boat and the coast. Some inhabitants of the douars in the surrounding hills confirmed that a luminous effect appeared around them. More optical features were observed in Agadir itself, at the moment of the interruption of the electrical power, which could be due to court-circuits. These phenomena, the possibility of submarine volcanic eruption, the tidal wave and the sulphurous small reported during the earthquake could not be verified (Choubert and Faure-Muret, 1962).

Agadir, normally a centre of tourism, became suddenly a setting of horror. The earthquake terrified the whole population exceedingly. Witnesses accounted: «... we got ready to go to bed when our house was uplifted and then violently shaken during 10 to 15 s which seemed endless. We were immersed in a total darkness. Furniture were overturning in the rooms, objects thrown from shelves and walls to the ground. The walls were crashing a dreadful sound. The doors were obstructed, but the windows were shattered to the ground. Finally, pushed by a total panic, we run in the dark streets full of rubble, sometimes obstructed by the destroyed buildings, only the light of a fire illuminated dimly our way. From the rubble, cries of terror were heard from all the directions, it was a tremendous and distressing clamour...». The oscillations were in the east-west direction (Press, 1960). In the Kasbah, the oldest quarter of the city, the building stock was completely destroyed (100 percent) as reported by numerous sources of information. The electric transformer station was the only structure that was still standing after the earthquake. The houses of this district were no more than a heap of ruins. The surrounding walls of the old part of the Kasbah had lost their crenels and upper parts. On the west col of this quarter, the village of Adouar was destroyed also at 100 percent. In the district of Yachech, a poor suburb built on the slopes of the Tildi Ravine to the northeast of Talborjt, the shaking was strong enough to put to the ground all the structures. Some sources reported that in the Kasbah and Yachech, the death toll approached 95 percent which we could not verify. As in the last two quarters, at Founti, a district built between 1920 and 1930 which is believed to be the ancient site of the Portuguese town of Santa Cruz de Aguer, almost all the constructions experienced total destruction (100 percent). In Talborjt, the buildings built between 1935 and 1950 were similar to those in Founti, the destruction was also very high, about 95 percent. The maternity wing of the Lyautey Hospital collapsed completely but, fortunately, it remained standing for 5 min after the shaking, allowing time for its evacuation before the final collapse, and so no one was hurt. In the Administrative Plateau, in spite of the relatively well built structures, the shaking was strong enough to destroy about 70 percent of the buildings. In the quarter of Front-De-Mer, the modern reinforced concrete hotels and apartment blocks had collapse in total ruin trapping hundreds of survivors under the heaps of tangled concrete and steel. One of the most spectacular structure collapse in Agadir was that of the called «Immeuble Consulaire». It consisted of an eight story high office and flat blocks, built in 1954, which accommodated at the time of the disaster about 300 people. Hotel Saada, which was the most publicised because of its occupancy by Americans and Europeans during the earthquake. This structure, which was built in 1952, collapsed completely, leaving the floor slabs piled one on another in «pancake collapse». Another famous building, Hotel Gautier, experienced «pancake collapse». In Ville Nouvelle (New City), where the constructions consisted of modern European type office buildings and flats, several structures suffered also «pancake collapse» in which hundreds of people perished. The «Sud Building» sustained heavy damage. The Municipal Market (City Market), which was a reinforced concrete frame structure, did not behave well during the shaking. The roof of the upper structure collapsed completely and serious damage to the second story floor system resulting from collapse of the roof. The water mains were cut off in many places (Press Reports). In the industrial zone (south), an area assigned to canneries and food processing plants, the shock destroyed about 30 percent of the constructions and damaged much more. Numerous houses were completely destroyed in the industrial district south. The industrial zone (north) which contains Anza and Arhesdis, is an area of fish canneries and also include a cement factory, flour mill plants and an electric power station, the earthquake cause only slight damage, about 5 percent. In the harbour zone, all the structures were built on filled ground, and only in this zone did the foundation and soil play a significant part in the damage. Most damage was related to fill subsidence. Several cranes overturned as the result of differential settlements. The blocks of concrete which constituted the piers were displaced sometimes up to 75 cm and disjoined. In Agadir, in addition to typical buildings, there was a number of special structures which were of interest according to their behaviour during the earthquake. The most famous is the restaurant «La Reserve» which was built on the beach of Agadir. The plan form of the building consisted of three intersecting circles, each about nine metres in diameter. The deck of the structure was supported at a height of about 3.6 m by a tapered column under the centre of each circular segment of the structure. The structure collapsed completely. The other special building which attracted attention was the Customs House which was located very near the harbour. It consisted of a 24 m diameter reinforced concrete shell structure supported by many tapered columns. Seven kilometres south of Agadir, at Ben Sergao, the army barracks were seriously shaken and the stone houses significantly cracked. Particularly, the control tower suffered considerably and was classified as unusable and dangerous. Despite the relatively small area affected by this earthquake, it is worthy of note that not all the damage was confined to city limits. Numerous other villages around Agadir sustained heavy damage, notably those in the mountainous zone to the north and northeast of the city, and about 600 of their inhabitants lost their lives. Within 12 km radius, the destruction of the local traditional houses (adobe structures) was complete, but the intensity of damage decreased rapidly beyond this zone. The extent of the damage is well reflected by the death toll. In the region of Inezgane, several tens of people were reported killed in the village of Tildi, 72 in Tagadir des Ait Lamine, 62 in Anou n'Feg which was completely destroyed, 28 in Taourirt and 12 to 15 in Iferkes. In the village of Taddert Ougadir (two km east of the cement plant) at least 15 people were killed. In the villages or Hamlets of Aourir-Assersif, 221 people had lost their lives. In the Ida ou Tanane, 130 deaths were reported in the village of Tagadirt Oufella which was completely destroyed, 43 in Immi Mikki which was seriously affected and 7 or 8 at Ait M'hamed. On the periphery of Djebel Lgouz (Mesguina), the destructions became partial; as in the northern flank and the village of El Ma, they decreased rapidly, particularly, in the valley of Oued Tamrhakht where the forest house exhibited only slight cracks. On the seashore, approaching Tarhzout, the damage was insignificant. In the east, the damage decreased towards the valley of Oued Lahouar; beyond this, there had been only two deaths in the village of Amalou. On the other hand, in the southeast of Agadir, in the plain of Souss, the destructions were very much slight and the zone affected is far more reduced. Damage is insignificant in the village of Ait Melloul (15 km of Agadir) and at El Klea (22 km of Agadir). The effects of the earthquake are little more important between the route of Tiznit and the seashore. Few constructions are destroyed in the Kasbah El tahar on the left bank of Souss (3 km south Inezgane), as well as the guard post of Tifnit which is located on the seashore at 25 km of Agadir.

Meanwhile, although the extent of the devastation caused by the shaking was almost complete (80 to 100 percent) in Agadir, there was a certain number of buildings and parts of structures which did not experience any significant structural damage, such as the cement plant, moulin du littoral, «Credit Populaire du Maroc» buildings among others. Some public works did behave very well during the shaking, particularly a reinforced concrete bridge and an aqueduct. The shock affected structures, with intensity V^{+} (MSK), in the zone comprised between Ounarha, Es-Saouira, Imi N'Tanout, Taroudannt, Ait Baha and the coast. Radius of perceptibility was fairly large, the shock was intensely felt up to Tiznit in the south and Bou Azzer in the east. In the southeast, it was observed in Bou Isakarne (150 km away), but was not felt in Foum El Hassane (180 km distant). On the other hand, it was perceived at Ouarzazate (400 km away). North of the Atlas, it was clearly felt up to Casablanca. The search for additional details of the extent of the damage continues.

7. Intensity re-evaluation

Using all the macroseismic information retrieved from various sources available to us, intensities have been re-evaluated anew with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale. It has been relatively easy to assign intensities to the different districts of Agadir and its immediate surroundings; this was made possible by the good description of the earthquake in numerous contemporary documents.

According to the history of the zone affected, the building stock exposed to the shaking consisted mostly of structural types A and B, and a small percentage of type C as defined in the MSK intensity scale. After a detailed study of the macroseismic data collected, maximum intensity exhibited has been re-evaluated at I_0 = X (MSK) and allocated to Founti, Kasba, Adouar, Talborjt, Yachech and their close vicinities. Intensity IX has been assigned to Ville Nouvelle, Administrative Plateau, Tildi and the harbour. Intensities X and IX have been attributed to the sites associated with total destruction and loss of life. Intensity VIII has been confined to the industrial quarter (south), Ben Sergao, Anou n'Feg, Ait Mehand, Tagadirt des Ait Lamine, Assersif, Aourir, Idourane, Taourirt Oufella, Za Immi Mikki, Tadert Ougadir, Anza and Arhesdis. Intensity VII has been assigned to Inezgane, army barracks, Taourirt ait Ahmed, Amalou, Tabadkoukt, El Ma and their surroundings. Intensity VI has been allocated to the area containing Kasba Tahar, El Mhasser and Tamrhakht. Intensity V has been attributed to the zone between Ounarha, Es-Saouira, Tamanar, Immouzer, Imi N'Tanout, Argana, Taroundannt, Ait Baha and their close vicinities. Intensity IV has been confined to Oualidia, Meddouza, Marrakech, Amizmiz, Irherm, Tafraoute, Anzi and Tiznit. Intensity III has been attributed to the zones included between Casablanca, Berrichid, Ouarzazate, Bou Azzer, Foum Zguid and Ifni.

From the intensity data, an isoseismal map of the Agadir 29 February 1960 earthquake has been constructed and is shown in figs. 8 and 9. Figure 8 presents the isoseismal map of the epicentral zone and fig. 9, the isoseismal map of the whole affected area.

8. Foreshocks and aftershocks

The main shock was preceded by two minor foreshocks. The first one, which occurred on 23 February 1960 at 12 h 16 min (GMT), was slightly felt. The second one occurred at 11 h 45 min on the 29th February, it was felt by every body in Agadir (V MSK) and caused some alarm among the population. In the other hand, a hundred of aftershocks were felt in Agadir during the months of March and April, but only six of them were recorded in the seismological station of Averroes (Debrach, 1962). The largest aftershock occurred on 1st March at 1 h 2 min (one hour and twenty minutes after the main shock), it was of less intensity but strong enough to achieve the destruction of many walls and partitions.

9. Discussion

In terms of the seismic history of Morocco reported by Sieberg (1932), Roux (1934) and Debrach (1952), the country has a long history of seismic activity. However, it is not a region where frequent catastrophic earthquakes occurred, although, past seismic events, which were not really significant, caused damage many times. According to a not precise document of Hoff (1840) where he stated: «... 1731: Ein Erdbeben verwustet die Stadt Sainte-Croix in Morocco...» (after Verneur, Journal des Voyages, t. XV, p. 50), Agadir (Sainte-Croix was identified as Santa Cruz by Roux in 1934) would have been destroyed in 1731, but no details of the damage nor casualties are known. For more than two centuries prior to the Agadir event, there had been no real destructive event in the coun-

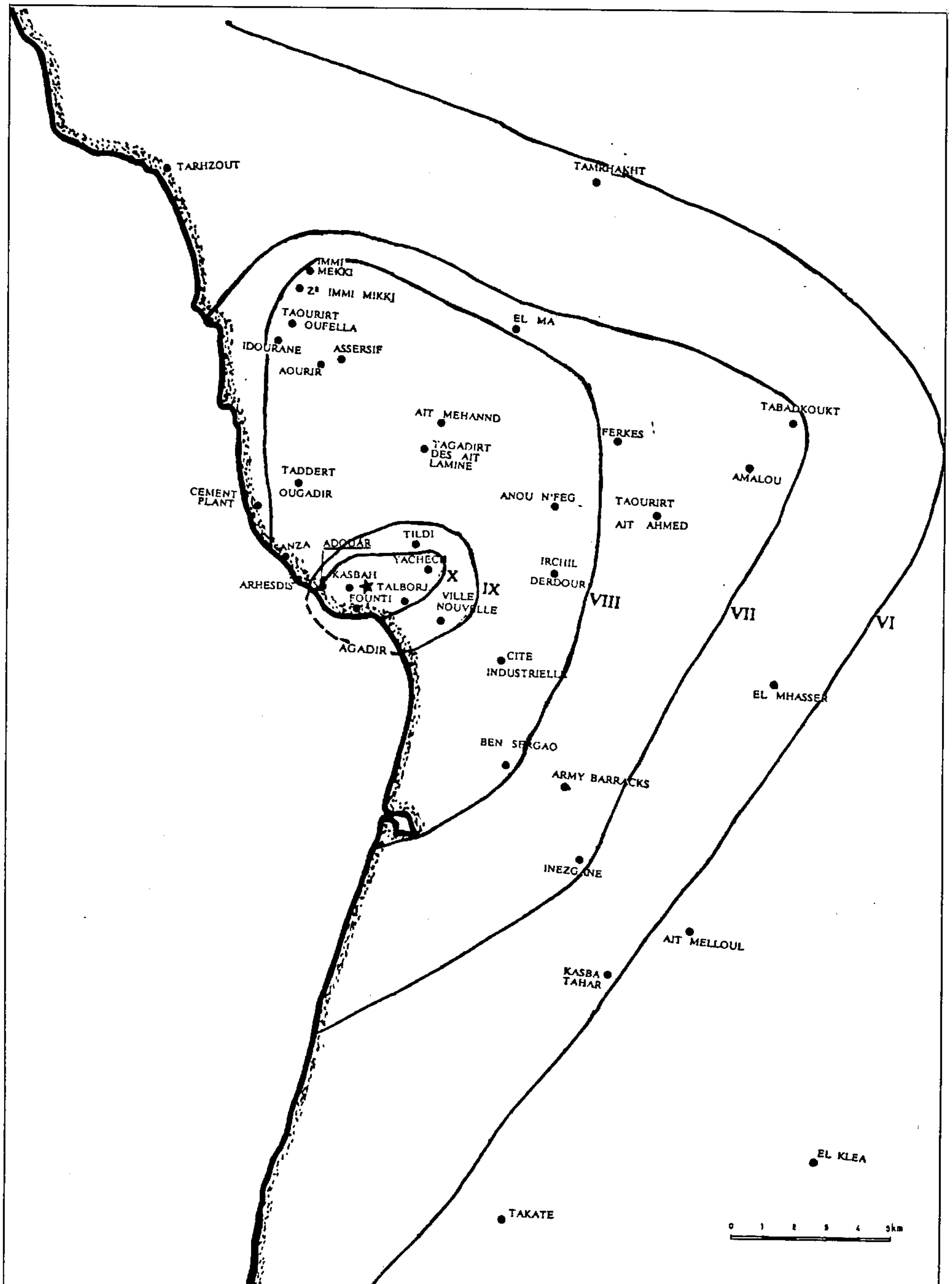

Fig. 8. Isoseismal map of Intensities VI^{+} (in terms of MSK scale) of the main shock of the 29 February 1960 Agadir earthquake. The star shows the macroseismic epicentre of the main shock.

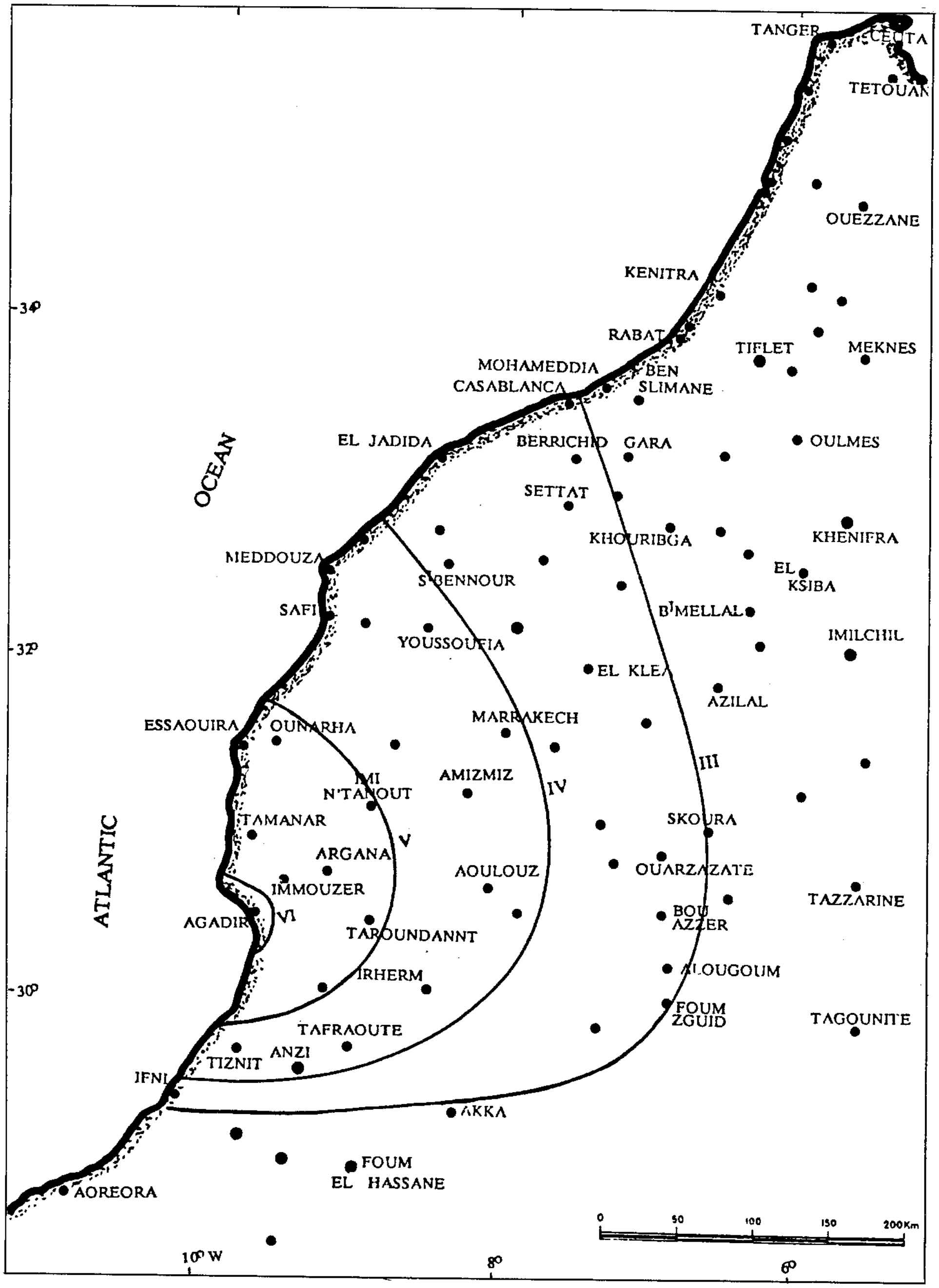

Fig. 9. Isoseismal map of Intensities III to VI (in terms of MSK scale) of the main shock of the 29 February 1960 Agadir earthquake. The star shows the macroseismic epicentre of the main shock.

try. Thus, this earthquake, which constitutes the largest felt and recorded seismic event during the last two hundred years, was rather an unattended one. Therefore, it is not surprising that no specific measures were taken against seismic risk in design and constructions of buildings in the region. The Agadir earthquake of 1960 shows the possibilities for a higher degree of spatial and time inhomogeneity of seismicity in the High Atlas ranges and the consequences of this in the evaluation of seismic hazard and risk in Morocco.

The reconstruction of the macroseismic field of Agadir earthquake of 29 February 1960 is of great importance for the region for various reasons. Firstly, it constitutes the largest recorded and felt seismic event in Morocco. Secondly, because of the extent of the devastation caused by this brief and localized earthquake, which was not a large one in terms of magnitude, makes it important to study. Thirdly, the same epicentral area displays today many of the human and geographical characteristics met in other parts of the country. For these main reasons, a detailed study of the effects of this earthquake on humans, man-made structures and on the ground itself is pertinent to whole Morocco, in terms of seismic hazard and risk establishments. It provides a fundamental basis for the reduction of future seismic catastrophes by recommending new ways of improving local construction procedures, building materials, properly strengthening and repairing existing structures, layout and implementation of new urban and rural settlements.

As in other past destructive earthquakes in the Maghreb region, we remark the ease with which local traditional dwellings, unreinforced masonry structures and even modern buildings were destroyed. Several modern buildings suffered «pancake collapse» as Hotel Saada, «Immeuble Consulaire» and Hotel Gautier in which hundreds of people perished under the rubble. Certainly, the vertical acceleration component was very important; walls and columns could not support the additional earthquake load. A general conclusion that may be drawn about the Agadir constructions is therefore their inherent strength is very low and variable and their vulnerability extremely high. Since no aseismic measure was taken in designing and constructing the buildings, the extent of the damage was rather the result of the deficiency in the structures than the severity of the ground shaking.

Summarizing the results, we obtain the following data for the 29 February 1960 earthquake: origin time: 23 h 41 min (GMT); instrumental epicentre at 30.57°N, 9.43°W (ISS); macroseismic epicentre at 30.52°N, 9.52°W (this study); maximum intensity I_0 = X (MSK); magnitude $M_S = 5.70$ ($\pm$ 0.23).

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The M'sila earthquake of 1 January 1965

Abstract
This research presents the study of the largest earthquake which occurred in the Hodna plains during this century. The M'sila earthquake of 1 January 1965 has been the largest recorded event in Algeria since 1954. It caused damage to a small area, of about 40 km radius, which M'sila was the centre. The earthquake, which lasted 6 to 7 s, caused at least a loss of 5 lives, injuring about 25 others and destroying or seriously damaging 3145 housing units; it rendered more than 25000 homeless at M'sila and its surroundings douars. We learned from reports that the damage was due, not only, to the earthquake but also to the torrential rain that the region experienced during that period. After considerable analysis of the macroseismic data extracted from various sources, we re-estimated maximum intensity at I_0 = VIII (MSK). It covered the town of M'sila and its surroundings, an area of about 11 km radius. The main shock was felt in a relatively small area, of about 300 km long and 200 km large. This earthquake is classified as a shallow moderate event with a focal depth of about 10 km. Its surface-wave magnitude was determined, without station corrections, at 5.45 (± 0.20). The macroseismic epicentre was re-estimated at the douars of Kherbet Tellis and Chettaoua which form the west part of M'sila at 35.712°N, 4.494°E. Analysis and full study of major historical events are of fundamental importance in the seismic hazard assessment in Algeria where large earthquakes are not frequent.

1. Introduction

By its size and the damage affected to the region, the M'sila earthquake of 1 January 1965 constitutes the most important recorded event in Algeria since Orléansville 1954 earthquake. In terms of the history of Algeria, however, it was by no means an exceptional earthquake. The same region, the Hodna plains have experienced many destructive earthquakes in the past (Chesneau, 1892; Rothé, 1950 and Press reports). Beside this earthquake, two other major seismic disasters occurred this century (Berhoum 12 February 1946 and Melouza 21 February 1960 earthquake), both focus in the neighbourhood of M'sila on the southern flank of the anticlinal axis of the Hodna. Detailed documentation of these catastrophic events provides a fundamental tool for the mitigation of future disasters by suggesting ways of improving local construction procedures, materials, layout and implantation of new villages. The Hodna plain, situated in the epicentral region of the M'sila earthquake, displays today many of the geographical and human characteristics found in other seismic parts of Algeria. A detailed and careful analysis of the impacts of the 1965 earthquake in this restricted region is therefore pertinent to Eastern Algeria and the country as a whole.

The M'sila earthquake occurred at 21 h 38 min 32 s (GMT) on 1 January 1965 in the region of the Hodna plain (fig. 1). This destructive earthquake struck M'sila and its surrounding villages and douars causing the

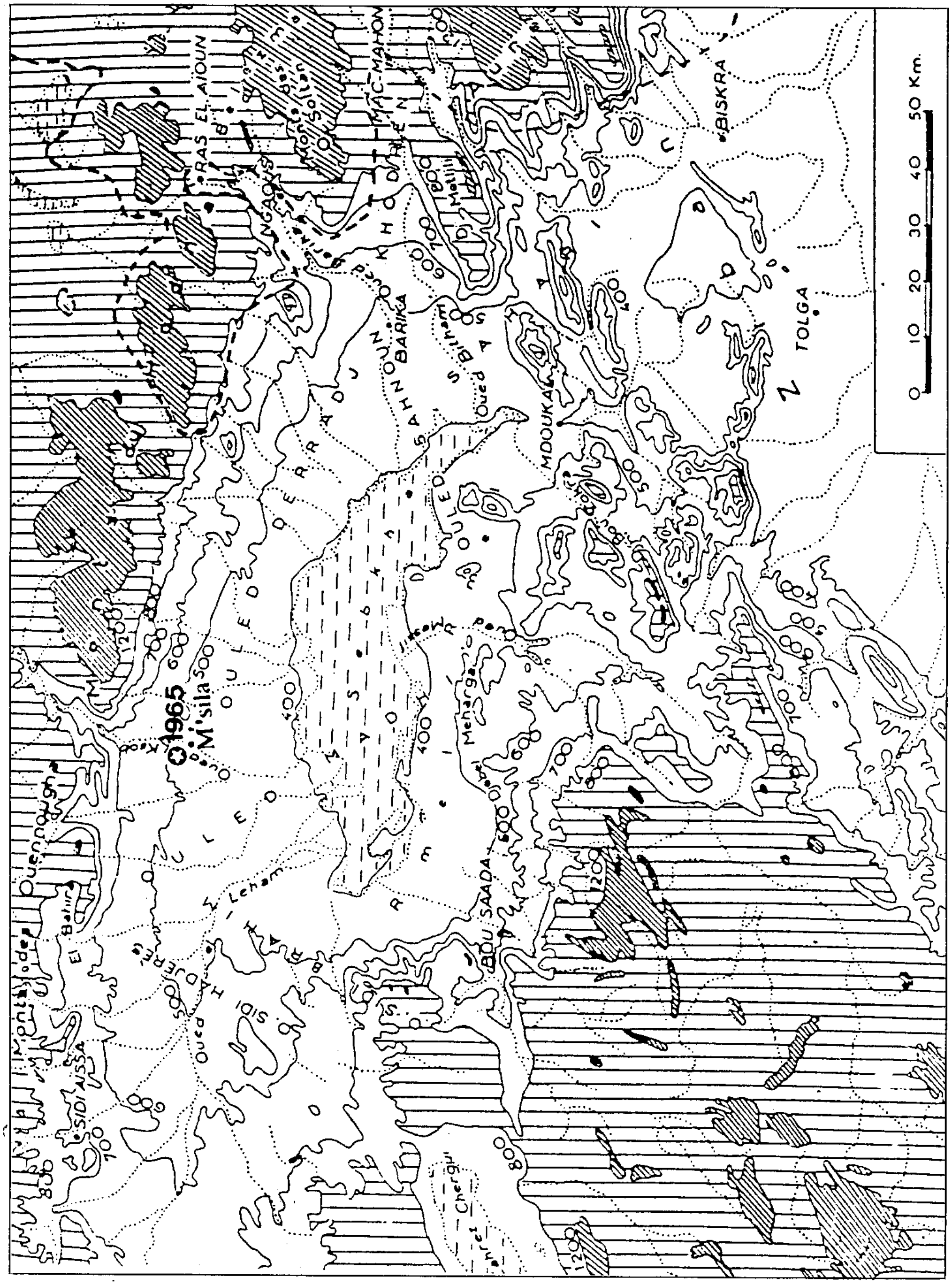

Fig. 1. Map of the Hodna plain and its surrounding mountains. The star shows the macroseismic epicentre of the main shock of the 1 January 1965 earthquake.

killing of at least 5 people and injuring more than 25 others. The main shock with its early aftershocks destroyed or badly damaged 3145 housing units rendering more than 25000 homeless. The main shock was recorded by most of the seismological stations operating at the time, 162 stations reported the event (ISC, 1965). The earthquake was preceded by a strong foreshock, the same day at 17 h 32 min, which caused total panic in the population and, cracks in some houses and followed by a long sequence of aftershocks (68 recorded at the seismological station of Setif during January in which 30 throughout the first 3 days).

The earthquake was reported to be felt, in an area of about 60000 square km, as far as Alger (strongly in high rise buildings), Medea, Trolard Taza, Hassi Bahbah, Ben Srour, N'gaous, Setif, El Kseur and Bordj Menaiel. The main shock, which lasted 6 to 7 s, had devastating effects on the old parts of M'sila. Its surface-wave magnitude was calculated at 5.45 ($\pm$ 0.20). The largest settlements completely destroyed or damaged beyond repair were Kherbet Tellis and Kraghna, west part of M'sila. Damage was also reported in other many surrounding douars. According to the macroseismic data available and after a careful analysis, maximum intensity was re-estimated at I_0 = VIII (MSK) at the town of M'sila and its suburbs, an area of about 11 km radius.

2. Sources of information

A comprehensive search for documents relative to the M'sila earthquake was carried out in many libraries and archives in both Algeria and England. The macroseismic data extracted from the variety of sources available have greatly contributed to the reconstruction of this important event in all its aspects. Because of its size and the period of occurrence, this earthquake was widely reported by the Algerian and International press. These press reports are of great importance in re-evaluating the effects of the earthquake on humans, man-made structures and, the ground itself and also in establishing chronology.

Despite the particular importance of this event to the Hodna region, it was studied only by Grandjean *et al.* (1966). They described briefly the effects of the earthquake, assigned a maximum intensity I_0 = VII (MS) at M'sila and, its suburb (an area of about 11 km radius) and published an isoseismal map (fig. 2). Their work is the sole source of macroseismic information used by Rothé (1969). Benhallou (1985), without quoting his source, published an isoseismal map (fig. 3) which seems to be the same as that of Grandjean *et al.* (1966). Maximum intensity was assigned at I_0 = VII (MSK), (SSIS) and I_0 = VIII (MM), (IMPGA-BCIS).

The 1965 M'sila earthquake was widely recorded. Instrumental epicentre locations were calculated at 35.61°N, 4.42°E (ISC); 35.40°N, 4.50°E (MDD); 35.70°N, 4.40°E (USCGS, BCIS); 35.70°N, 4.50°E (MOS); 35.71°N, 4.43°E (MOX); 36.50°N, 4.40°E (PRA); 35.7°N, 4.5°E (SSIS (1965), Mezcua and Martinez, 1983).

Numerous agencies and seismological stations have also assigned magnitudes to this event: $M = 5.5$ (BCIS); $M = 5.2$ (SSIS); $m_b = 5.2$ (USCGS); $m_b = 5.1$ (ISC); $M = 4.9$ (Collemberg); MLH = 5.4 (KRA); MLH = 5.5, MLV = 5.3 (MOX); $M = 5.50$ (MOS); $M = 5.3$ (PRU); $M = 5.3$ (PRA); $M = 5.1$ (HRB); $M = 4.8$ (SPC) and $m_b = 5.2$ (Mezcua and Martinez, 1983).

In what follows, we present a summary of the analysis of these documents and the resultant damage of the event.

3. Geographical aspects of the epicentral region

The affected region lies within the Hodna plains which is about 200 km southeast of the capital Alger and 100 km southwest of Setif. The epicentral area is located

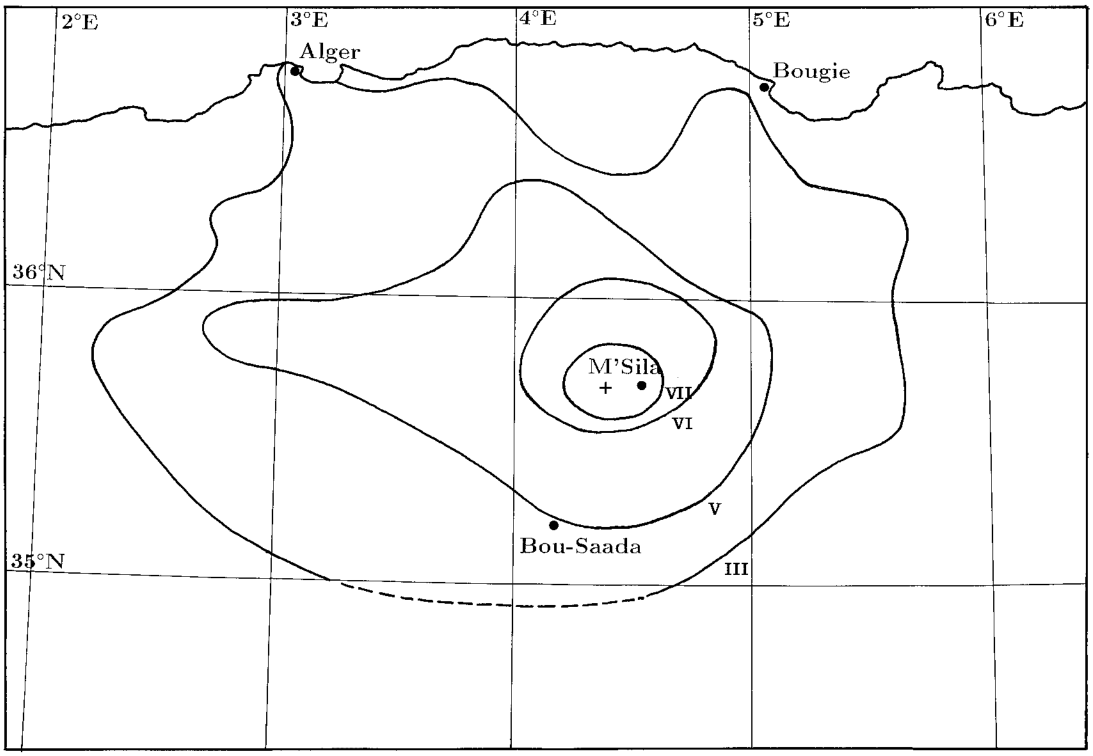

Fig. 2. Isoseismal map (in terms of MS scale) of the main shock of the 1 January 1965 earthquake, after Grandjean (1966). *Redrawn.*

on the southern flank of the anticlinal axis of the Hodna ranges.

M'sila, chief-town of the district, a city of 32000 inhabitants is situated on the southern flank of the Hodna massif which is itself an integral part of the Tell Atlas. It was founded by the Fatimides, dynasty of Ifrikiya which had its headquarters in Tunisia, in 925/6, 3.5 km northwest of the ruins of the antique Zabi, as a military strategic base. With time, M'sila lost its military character but, fortunately, the region and particularly its site had allowed the city to survive the wars and the abuse of the nomads. M'sila occupies a remarkable position compared to the rest of the region, regarding the depression that Oued Ksob opened in the direction of Medjana, last passage, in the west, toward the high plains of eastern Algeria. M'sila had been always crossed by an important road which made it the capital of the Hodna. This road crossed the plain from east to west, north of the Sebkha since the antiquity.

The nucleus of the old M'sila is composed mainly by three douars on the west bank of Oued Ksob (photograph 1): douar Kherbet Tellis, douar Chettaoua and douar Kraghla. Douar Kherbet Tellis in the south which is known as the initial core of the town. The sites of two doors (bab) of the old M'sila: Bab Ben Djerad in the west and Bab Es Souk in the east with oil merchants shops were still visible (Despois, 1953) before the filling works buried them. Chettaoua, joined side by side to Kherbet Tellis

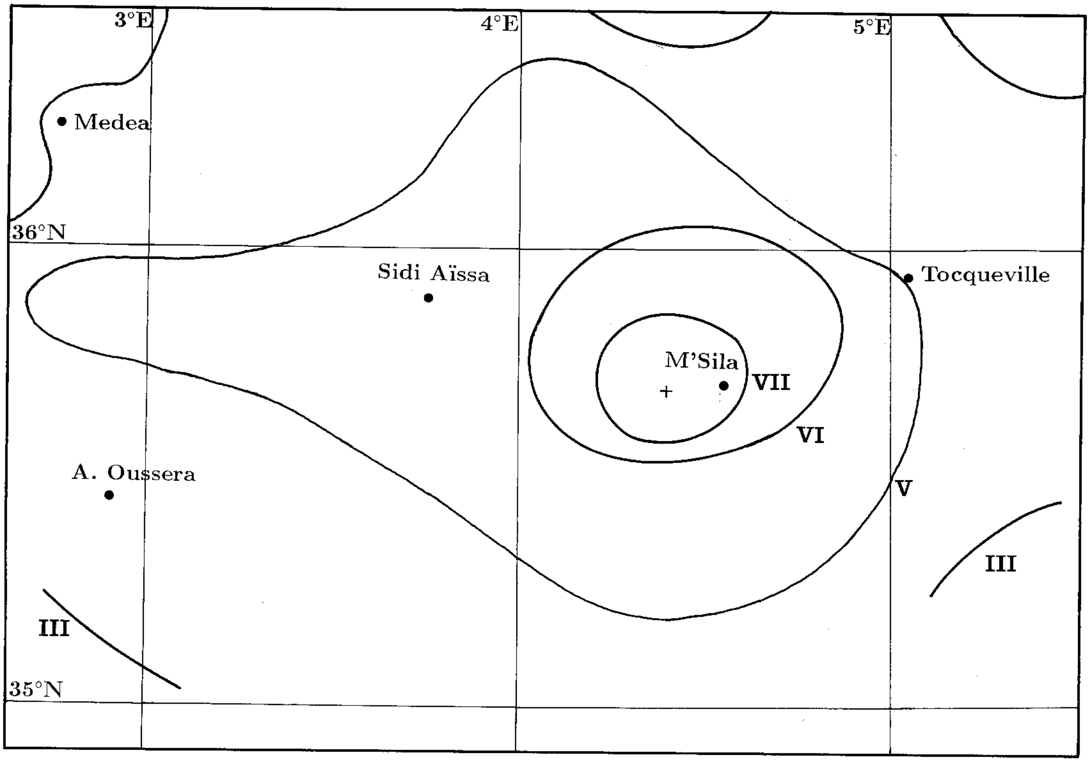

Fig. 3. Isoseismal map (in terms of MM scale) of the main shock of the 1 January 1965 earthquake, after Benhallou (1985). *Redrawn.*

is also an old douar. According to the region history, it is obvious that M'sila in the Xth century was larger than Kherbet Tellis and Chettaoua together; it had suffered a lot and should have been partly demolished more than once during its existence probably by earthquakes (Despois, 1953). Vestiges of impounding of water and antique canalizations still remain near all important springs notably at N'gaous and Berhoum. Also, several remnants of the past as dams, quanats and ruins of Kalaat Beni Hammad still exist in the Hodna (Gsell, 1902) and should be studied in details for an eventual reveal of historical earthquakes in the region. North of the actual road of Selman, a third douar, Kraghla or Ras El Hara (head of the Jew douar), built during the Turkish times and was inhabited by the Kouloughli families (families of Turkish father and native mother).

M'sila had lived, before the XVIth century, hard times but also long periods of prosperity. When the French arrived in the Hodna, in the middle of the XIXth century, M'sila was vegetating for the last 400 years and the third of its constructions were in ruins (Despois, 1953). During the French presence M'sila did not know any development and was kept for semi-arid agriculture. Unemployment and impoverishment were the main characteristics during the French occupation. After the 1965 earthquake, M'sila has gained a government special programme for reconstruction and development.

Photograph 1. Arcial photograph showing some parts of the town of M'sila.

4. Damage and casualty distributions

The information provided by all the sources available have been used in the re-evaluation of the damage and the re-estimation of intensity. The macroseismic data available have greatly contributed in the re-evaluation of the effects of the earthquake on humans, constructions and the ground itself. The immediate consequences of the earthquake are measured in terms of casualty rate and destroyed or irreparably damaged constructions. All the sources available concentrate on the complete destruction of the douars of Kherbet Tellis and Kraghna which constitute the oldest parts of M'sila. The main shock, preceded by a strong foreshock at 17 h 32 min, which in the epicentral zone lasted 6 to 7 s and its early aftershocks killed 5 people and injured 25 others. It destroyed or badly damaged beyond repair about 3145 housing units rendering approximately 25000 homeless.

It is very important to mention that M'sila and its surroundings have experienced a torrential rain before and after the earthquake which accentuated the disaster.

At M'sila, 6 shakings were felt, on 1 January 1965 at 17 h 32 min, 21 h 38 min, 22 h 30 min and, on the 2 January at 2 h, 5 h and 7 h, causing a general panic and significant damage to the town and its surroundings, an area of about 40 km radius. In fact, all the population had left their homes to the streets, stadium or cemetery. The damage was reported as 1304 housing units were totally destroyed, 673 threatening of collapse and 687 heavily cracked. About 17815 homeless people were living in relief camps around M'sila alone. A witness was reported as saying: «... I have seen the sky red as a blaze. I was at home on this Saturday 1 January when at 17 h 32 min, I saw a strong lightening followed by a rumbling similar to that of a thunder. First I felt the ground shaking and then I heard the walls cracking. Fearing of the collapse of my house, I rushed outside to the open followed by my children and my wife. The atmosphere was smelling sulphur gas and the sky was red. We left the town and, despite the torrential rain and the cold we spent the night in the open...». Many people after this shaking returned home but, fortunately, only 4 hours later at 21 h 38 min, when people were still awake and in alert, a violent shock struck M'sila destroying most of its constructions. Again the population had to flee from their collapsed or seriously damaged houses to the open, this time to spend the night, fearing another shock. «... We do not know how it happened so suddenly declared an inhabitant of M'sila, still deeply affected. Particularly, the second shock of 21 h 38 min which caused the shaking and the cracking of everything around us. I had taken my children and my wife and rushed in the streets. We spent the night, despite the rain and the cold, in the cemetery. When I went back home in the next morning, everything was broken and particularly the walls were seriously damaged...». The majority of the constructions at M'sila as other parts of Algeria were built simply by a mixture of mud and straw, sundried mud bricks or only dry-stones and generally covered with a thatched roof surcharged with heavy rocks to resist the winds. The gourbis with free weak walls (not bound to each other) and heavy roof could not resist the earthquake. In the douars of Kherbet Tellis and Kraghna where the old houses had suffered considerable deterioration through ageing, improper repair, heavy rains, wars and earthquakes, but generally through neglect and lack of proper repair, were most vulnerable; they were shattered in a total jumble. Photographs taken after the earthquake show the magnitude of the damage to the housing units. The houses in these douars were built side by side (as in Alger-Casbah houses are tied together to resist better the shakings) but, unfortunately, this procedure at M'sila increased the destruction. Houses brought down by the earthquake fell against the ones by their sides accentuated their damage or simply completed their collapse. These houses were seldom more than three storeys high and generally only one. They had thick brittle walls, particularly drystone, heavy floors and roof with loose or no connection between these elements. It is in the old parts of the town that these conditions were more evident. Some of the old houses destroyed by the earthquake were uninhabited (abandoned) as their occupants had migrated to big cities when the French left Algeria in 1962.

The Mosque of the town was completely destroyed. The newly built apartment blocks, of which its inhabitants had fled after the shaking, were threatening of collapse whereas the city hall, just completed at a cost of 900000 DA (Algerian Dinars), was seriously cracked. Constructions that did not suffer destruction had seen their furniture completely jumbled. We found no report of any ground deformations produced by the earthquake. The Oued Ksob Dam, sole masonry dam in the region, built on Ksob River at 15 km north of M'sila did not suffer any damage. Stone constructions, built downstream the dam, were cracked.

The fear was so big during the disaster that cases of paralysis, premature forced abortions and deliveries were reported at M'sila hospital. Furthermore damage was reported in other districts of the region at Chellal, Pelaa, M'cid, Misrir, Melouza, Ouled Mansour, Hammam Dhelma, Maadid, Ouled Deradj, Hammam Selai and Oukhnis where 480 housing units accommodating 6660 people were destroyed but no casualty was declared. Officially the Algerian authorities had reported that 70 houses were destroyed in the douar of M'cid, 80 in Ouled Deradj (20 km), 10 in Boukhmissa (20 km), 15 in Misrir, 70 in Ouled Mansour (45 km), 80 in Melouza (45 km), 36 in Maadid (25 km) and 40 Hammam Dhelma (35 km).

According to the distribution of the damage, the macroseismic epicentre is suggested to be at M'sila slightly west. At Boghari, 160 km west of M'sila, the earthquake was so strong to cause the population flee from their homes to the streets and public places but only slight damage was reported. In Boussaada, 62 km southwest of M'sila, during 30 s the shaking caused more fear than harm and only slight damage to old houses. Many people had left their homes. At Bouira, 95 km of north of M'sila, the shaking was seriously felt but no damage was declared. In Bordj Bou Arreridj, 45 km northeast of M'sila, the earthquake was strongly felt and only slight damage was caused to the town hospital. At Maillot and Beni Mansour, 65 km northeast of M'sila, the shaking was so strong that many people had to flee from their homes. 36 km north-northeast of M'sila, in the village of Lecourbe, which is built on impermeable clay alluvium, some major cracks in relatively well built constructions were produced.

The earthquake was also felt at Alger, particularly at Hussein-Dey and Leveilley (actually El Maquaria), where the population in a high rise building of 15 storeys had lived few hours of emotion. Just after the shaking (21 h 38 min), the inhabitants of the building had left their apartments to the streets fearing other shakings. According to some inhabitants of upper storeys, they had their furniture overturned. Three hours later, the inhabitants by small groups started to get back home. The shaking was slightly felt in Alger, Menerville, Bordj Menaiel, El Kseur, Setif, N'gaous, Ain Melh, Ben Srour, Hassi Bahbah, Ain Oussera, Trolard Taza and Medea (Grandjean *et al.*, 1966).

5. Intensity re-evaluation

Using the data provided by the various sources of information available to us, intensities were re-evaluated with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) scale.

A general conclusion about the typical house of the region, at that time, is that its inherent strength is very low, extremely variable and its vulnerability very high.

Thus, the level of damage to this type of construction is generally an indication of the weakness of the structure rather than the strength of the ground shaking.

For this event, it is very important to mention that M'sila and its region had experienced torrential rain just before and after the earthquake which disturbed the relief operation and increased the damage.

After much analysis of the damage and the prevailing conditions of the time of the disaster, maximum intensity was re-estimated at VIII (MSK) and was assigned to the town of M'sila and its surrounding douars. Intensity VII was attributed to Melouza, Ouled Deradj, Ouled Mansour, Douar M'cid, Chellal, Pelaa and Maadid. Intensity V allocated to Lecourbe, Mansoura, Bordj Khris, Beni Ilma, Sidi Aissa, Oukhnis and Boussaada. Intensity IV was assigned Alger (isolated), Bordj Bou Arreridj, Beni Mansour, Maillot, Boghari, Outlem and Bouira. Intensities III and IV were allocated to Menerville, El Kseur, Setif, N'gaous, Ben Srour, Hassi bahbah, Tolard Taza and Medea. Broadly, intensities VIII and VII were assigned within the zone that contains destroyed douars, slightly damaged good masonry and reinforced concrete structures and loss of life. Intensity V was allocated to sites where moderate to heavy damage was caused to the traditional constructions and people panicked and run outdoors. Lower intensities are based only on felt reports.

As a result of the analysis of the macroseismic data, an isoseismal map of the 1 January 1965 M'sila earthquake has been drawn and is shown in fig. 4.

6. Magnitude determination

The surface-wave magnitude of the earthquake has been calculated from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 11 stations located at distances between 15° and 33°, and a preliminary macroseismic epicentre at 35.712°N, 4.494°E. The data and the results are given in Benouar (1993). The mean period is 13 s and the derived value of M_S, without station corrections, is 5.45 (± 0.20).

7. Foreshocks and aftershocks

The 1965 M'sila earthquake was preceded by a strong foreshock the same day at 17 h 32 min 28 s. The shaking was strong enough to make people flee from their homes and cause cracks in some constructions at M'sila. The low rate of casualty recorded in this earthquake is due to the foreshock which alerted the inhabitants. Aware about the high vulnerability of their houses to earthquakes, many families did not get back to their dwellings. After considerable analysis of the damage caused by this foreshock, an intensity VI (MSK) was assigned to the epicentral zone: M'sila and its close surroundings. The USCGS has attributed a magnitude at M = 4.4 and an epicentral location at 35.75°N, 4.54°E.

In the other hand, the main shock was followed by a long sequence of aftershocks of less intensity and continuing until late January. 68 aftershocks were recorded at the seismological station of Setif during January 1965 in which 30 during the first three days. Of the largest aftershocks, some were particularly violent: 3 January at 8 h 15 min, 9 January at 21 h 36 min 26 s, 15 January at 23 h 47 min 29 s and the 28 at 3 h 26 min.

The largest aftershock occurred on 15 January 1965 at 23 h 47 min 29 s. It was almost as strongly felt as the main shock. This aftershock was recorded instrumentally by 88 seismological stations up to Brisbane about 152° away. The teleseismic data obtained do allow a surface-wave magnitude determination from 3 stations. The derived value of M_S is, without station corrections, 5.15 (0.11). The details are given in Benouar (1993). This aftershock did not increase the casualties but unfortunately did complete the collapse of many construc-

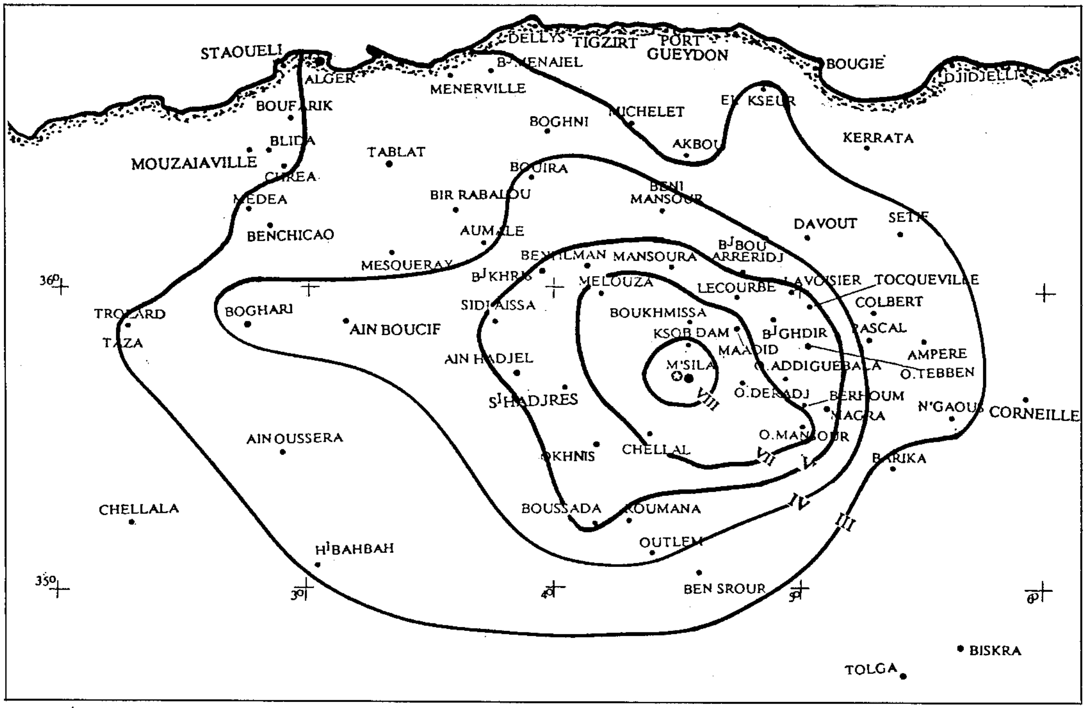

Fig. 4. Isoseismal map (in terms of MSK scale) of the main shock of the 1 January 1965 earthquake. The star shows the macroseismic epicentre of the main shock.

tions already weakened by the torrential rain and the shakings. Some agencies and seismological stations have assigned magnitudes to this aftershock: $M = 4.7$ (USCGS, ISC), MLH = 5.2; MLV = 5.0 (MOX), MLH = 4.9 (PRU), $M = 5.0$ (PRA), $M = 5.2$ (MDD), $M = 5.25$ (BCIS). The instrumental epicentre was located at 35.72°N, 4.33°E (MOX); 35.70°N, 4.30°E (PRU); 35.4°N, 4.5°E (MDD); 35.7°N, 4.3°E (USCGS); 35.7°N, 4.4°E (BCIS); 35.73°N, 4.32°E (ISC).

8. Discussion

The M'sila 1965 earthquake had shown the possibilities for a high degree of spatial and time inhomogeneity of seismicity in the Hodna and the consequences of this in the establishment of the seismic hazard in Algeria. Compilation and critical analysis of historical documents concerning the 1965 M'sila earthquake have led to the assessment of how much damage was produced and how it was felt by the population. As a result of this analysis, an isoseismal map has been drawn which shows that isoseismals are noticeably elongated along the main direction of the Hodna chain. We remark also, as for Berhoum 1946 and Melouza 1960 earthquakes, that the seismic waves were propagated more toward the west, further than Boghari, whereas they were more rapidly attenuated in the east.

The main shock was so strong to cause sufficient damage and panic to be largely reported in contemporary documents. Because of the sparsely distributed villages and douars in the valleys and up on the flanks of the mountains, many intermediate sites within the radius of perceptibility were not reported in any historical source. Low fatalities from the collapsed houses are mainly due to the premonitory shock of 1 January at 17 h 32 min 36 s which alerted the population of the region. Knowing that their constructions were highly vulnerable to earthquakes and even heavy rain, many families did not get back to their homes and so thousands of lives were saved. The extent of damage sustained to the constructions and particularly to the local «toub» houses was, not only, the result of the earthquakes but also of the torrential downpour rain that affected M'sila and its region. Most houses were already deteriorated by rain, wars, earthquakes and lack of proper repairs. Thus, it is not easy to consider the real damage produced by the earthquake alone. In the re-assessment of damage, a careful and critical analysis of all the parameters (rain, earthquakes, type of building stock,...) were necessary in order to obtain realistic intensity re-evaluation and avoid overrating. The town of M'sila is crossed by Oued Ksob of which the bed is contained into many metres of alluvial stony terrace that drain the surrounding permeable formations. The drained soil has adequately resisted to the shakings and it does not seem that we should take into account the small mass of fallen earth observed at the river bank or the cracks on the road which may have been caused by the rain rather than the earthquake itself (Grandjean *et al.*, 1966). Historical reports should be studied in the context of the political and socio-economic situation, cultural and religious backgrounds, demographic conditions and the characteristics of the building stock of the period concerned. As for this event, many houses destroyed by the earthquake were uninhabited (abandoned) as their occupants had migrated to big cities when the French left Algeria in 1962. The precarious socio-economic situation of the region which was characterized by the lack of factories, a semi-desert climate where the agriculture was scarce, unemployment, lack of adequate housing, schools and, hospitals and a fast growing population which was looking for a better life after the independence. The region of M'sila as most of interior villages and douars had experienced the rural depopulation. The living conditions in this particular region became worst after the 1 January 1965 disaster. The Algerian government aware of the socio-economic conditions of the region, the political consequences that may follow and the ongoing rural exodus which was accentuated by the earthquake, had provided M'sila with an important and special reconstruction and development programme.

In 1965, the young Algerian government was not prepared and did not have adequate means to deal with this kind of emergency. Fortunately, the Algerian people, still unified by the Liberation War (1954-1962), had shown a great solidarity and participation in the relief operations and donations for the victims. The earthquake had been largely related in the government newspapers showing a great concern of the authorities. The affected region was visited by the Minister of Social Affairs and the Minister of Reconstruction who gave some insurance to the victims about first-aid, food, shelters and particularly about reconstruction of M'sila. However, if the population were morally comforted by this visit, the situation was still alarming. The relief proved to be tiny comparatively with the extent of the disaster.

Detailed reconstruction of historical events are of fundamental importance in the establishment of the seismic hazard, particularly in regions where large earthquakes are not frequent.

Summarizing the results, we obtain the following final data for the 1 January 1965 M'sila earthquake: origin time 21 h 38 min 32 s (GMT); macroseismic epicentre at 35.712°N, 4.494°E; focal depth of about 10 km; intensity I_0 = VIII (MSK); magnitude $M_S = 5.45$ ($\pm$ 0.20).

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The El-Asnam earthquake of 10 October 1980

Abstract
This research presents the study of the largest earthquake recorded in the Central Cheliff Valley since 1716. On Friday 10 October 1980, at 12 h 24 min 24 s (GMT), a destructive earthquake occurred in the Central Cheliff Valley affecting a rather densely populated region of about 900000 people within 8000 km^2. The magnitude of the earthquake was re-calculated at M_S = 7.45 (± 0.33). The main shock and the largest aftershock (10 October 1980 at 15 h 39 min 9 s) caused the loss of 3000 lives, injuring more than 8500 and making 400000 homeless; they destroyed or seriously damaged at least 60000 housing units in 24 towns and villages. The extent of the socio-economic impacts of these events confirmed that Algerian buildings are highly vulnerable to the recurrence of destructive earthquakes. Maximum intensity reached is re-evaluated at I_0 = IX (MSK) scale at El-Asnam, Sendjas, Oued Fodda, Beni Rached, Zeboudja, El-Attaf, El-Abadia and Oum Drou. Radius of perceptibility was very large, the shock was felt as far as Bejaia (east), Laghouat (south), Tlemcen (west), and north up to Cordoba and Barcelona in Spain. A damaging aftershock and the largest, which magnitude was re-calculated at M_S = 6.2 (± 0.3), followed the main shock 3 hours later and added considerable casualties and damage to man-made structures and to the ground itself. The earthquake was followed by a long sequence of aftershocks; 9 tremors with magnitude M_S equal or greater than 5.0 were recorded during the period 10 October 1980 to 14 February 1981. This earthquake caused considerable economic losses to Algeria, had large socio-economic and psychological impacts on the region. The total cost of the damage has been estimated at around 5 billions U.S. Dollars.

1. Introduction

El-Asnam, the capital and the largest town of the Wilaya of El-Asnam, usually a centre of routine domestic life, became suddenly a setting of horror. On Friday 10 October 1980, at 12 h 24 min 24 s, a destructive earthquake struck El-Asnam and its surrounding villages causing the killing of at least 3000 people, injuring more than 8500 and making about 400000 homeless. It destroyed or seriously damaged about 60000 housing units in the whole affected area. The main shock was recorded by almost all the seismological stations operating at that time. Its magnitude was re-calculated at M_S = 7.4 (± 0.3). The earthquake, which lasted 35 to 40 s, had devastating effects on the whole community. It apparently seems that it was not preceded by any foreshock but other reported phenomena could have been premonitory. The main shock was followed by a long sequence of aftershocks during several months. The main shock and its strong aftershocks (9 with magnitude M_S equal or larger than 5.0, given in table I) caused widespread damage associated mostly with the high vulnerability of certain types of constructions. The largest aftershock, whose magnitude was re-calculated at M_S = 6.2 (0.3), occurred three hours later at 15 h

Table I. List of the aftershocks with surface-wave magnitude equal or larger than 5.0.

Date	Time (GMT)	Magnitude M_S
10 Oct. 1980	14:44:57	5.0 (± 0.25)
	15:39:13	6.2 (± 0.30)
	17:32:55	5.0 (± 0.20)
13 Oct. 1980	06:37:45	5.2 (± 0.30)
8 Nov. 1980	07:54:22	5.0 (± 0.23)
5 Dec. 1980	13:32:07	5.0 (± 0.23)
7 Dec. 1980	17:37:11	5.5 (± 0.35)
1 Feb. 1981	13:20:01	5.4 (± 0.22)
14 Feb. 1981	13:15:18	5.0 (± 0.28)

39 min 9 s (GMT) in the same area. It, not only, disrupted the relief operations but also increased dramatically the casualty toll and the damage caused by the main shock.

The main shock was widely felt in Algeria, within a radius of about 300 km, as far south as Laghouat, east as Bejaia and west as Tlemcen. The following region was officially declared sinistered: 1) Wilaya of El-Asnam: all the dairas (Counties or Boroughs); 2) Wilaya of Tiaret: Dairas of Tissemsilt, Beni Hendel and Theniet El Had; 3) Wilaya of Blida: Daira of Cherchell; 4) Wilaya of Mostaganem: Dairas of Oued Rhiou and Mazouna. The whole sinestered zone was put, by the same decree, under military commands. Up north of the affected region, the earthquake was felt in many southeastern and northeastern parts of Spain as far as Cordoba and Barcelona, (Ambraseys, 1981a,b and Press Report, 1980). We found no evidence that the earthquake was felt in Morocco. The details of the felt area are given in fig. 1. The main shock affected structures, with intensity V^+ (MSK), up to Valencia in Spain as shown in fig. 3.

The 1980 El-Asnam earthquake was associated with an extensive ground deformations; it is the first known event that produced large surface rupture in Western Mediterranean area. Details of observed ground features and their association with the tectonic environment of the region are given by Ambraseys (1981a,b). One of the remarkable effects of this earthquake is that an equivalent amount of both extensional and compressional deformations was observed which implies a rather complex deformation mechanism (fig. 2). It remained abundantly clear that damage to the surface as a result of the shaking was extensive, disastrous and varied. Much land was sunk and other was uplifted; lake was formed, flow of springs were altered, water levels in wells were modified and the courses of Oued Cheliff and Oued Fodda were changed. Fissures, large cracks, landslides, sand blows and extrusions of various kinds were common (Ambraseys, 1981a,b; Papastamatiou, 1981; Philip and Meghraoui, 1983).

The most reliable information on ground motion during an earthquake is obtained from recordings of strong-motion accelerographs. Unfortunately, the strong ground motion of the main shock of the 1980 El-Asnam earthquake, as well as that of the largest aftershock, was not recorded. However, a strong motion record was obtained from the aftershock of 8 November, 1980 of magnitude M_S = 5.0 (± 0.30). It is interesting to note that the largest vertical accel-

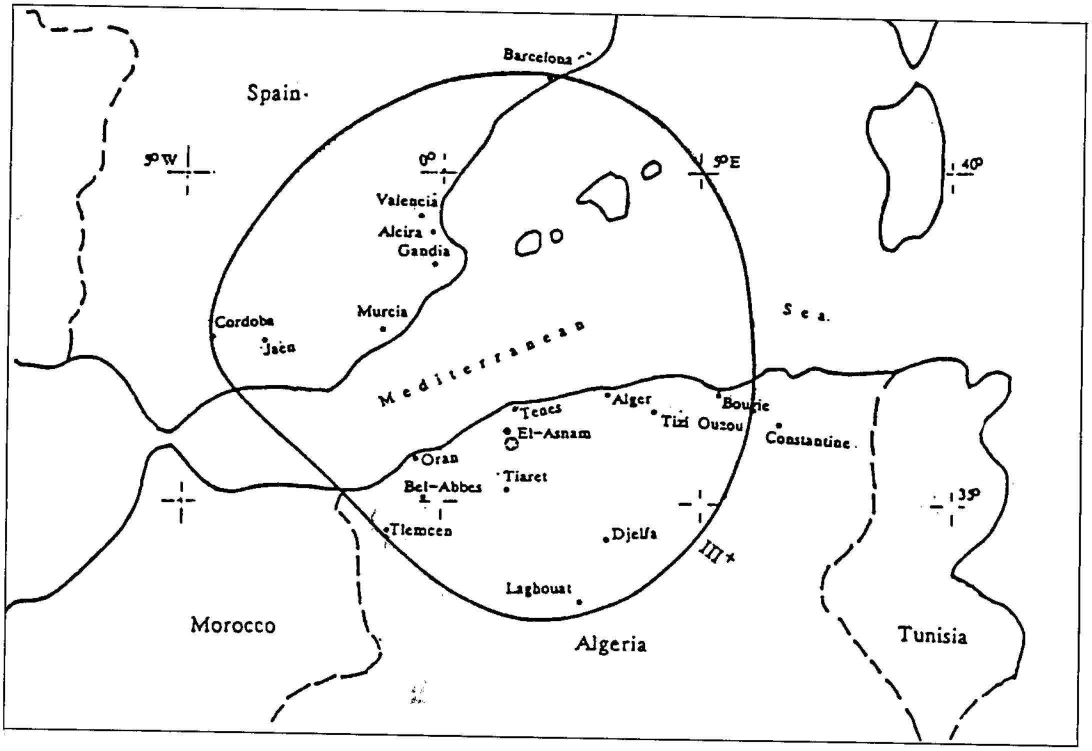


Fig. 1. Map of the felt area of El-Asnam, 10 October 1980 earthquake, showing the approximate zone of intensity III$^+$ (MSK). The open star shows the macroseismic epicentre of the main shock.

eration recorded was about 0.31 g and the largest horizontal component was about 0.21 g. The trend of predominant largest vertical component was observed in many other aftershock records. It is estimated that the main shock had an acceleration larger than 0.40 g in the horizontal direction and 0.50 g to g in the vertical direction (Papastamatiou, 1981).

By its size, the El-Asnam earthquake has been the largest event in the Maghreb region since 1790 and in the Cheliff valley since 1716. It occurred very close to the epicentre of the shock of 9 September 1954 (M_S = 6.7 (± 0.2)) which almost totally devastated Orleansville (actually El-Asnam) with the loss of at least 1409 lives. Furthermore, it was an unexpected earthquake, in contrast with the type of shock normally used as the basis for earthquake-resistant design of buildings (French recommendations AS 55 and PS 69 which were used in Algeria) and the theoretical estimates of the seismic hazard deduced from incomplete data sets which did not expect a predominant ground acceleration exceeding 0.35 g (Mortgat and Shah, 1978a,b).

2. Sources of information

The 1980 El-Asnam earthquake is very well documented with a variety of source materials. This large unexpected event has seriously reminded the Algerian authorities of the severity of the social, economic and even political impacts that seismic hazard can have on the whole of the country. After this earthquake disaster, the Algerian government, really shocked by the extent of the casualties, the damage and very much preoccupied by the reconstruction of the affected region, charged the National Organism for Scientific Research (ONRS) to organize an International Scientific Seminar on the 10 October, 1980 El-Asnam earthquake. Regarding the importance of the various features caused by the shaking, several national and foreign scientists have contributed to the analysis and understanding of this earthquake. This international meeting, which was held at Alger on 15-16 June 1981, has given the basis for the Algerian authorities to launch a national programme to mitigate the seismic risk (Appendix 1 in this report). The information available for this event is rich in details. A considerable amount of documentary materials, field reports, scientific works, general chronicles, local and, European press and special studies provide invaluable macroseismic and instrumental data. We did not see the necessity to describe each work individually; their comparative qualities and shortcomings emerge from the use made of them.

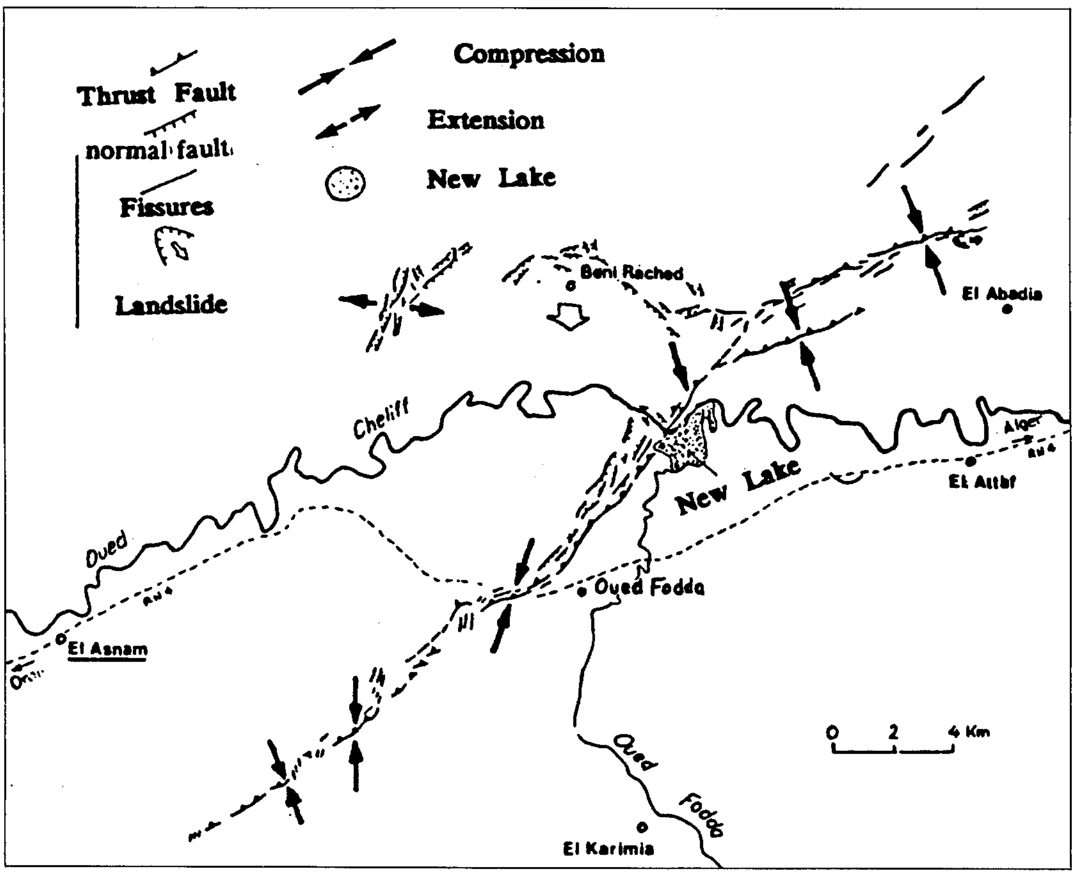


Fig. 2. Map showing the surface fault ruptures, after Meghraoui (1988).

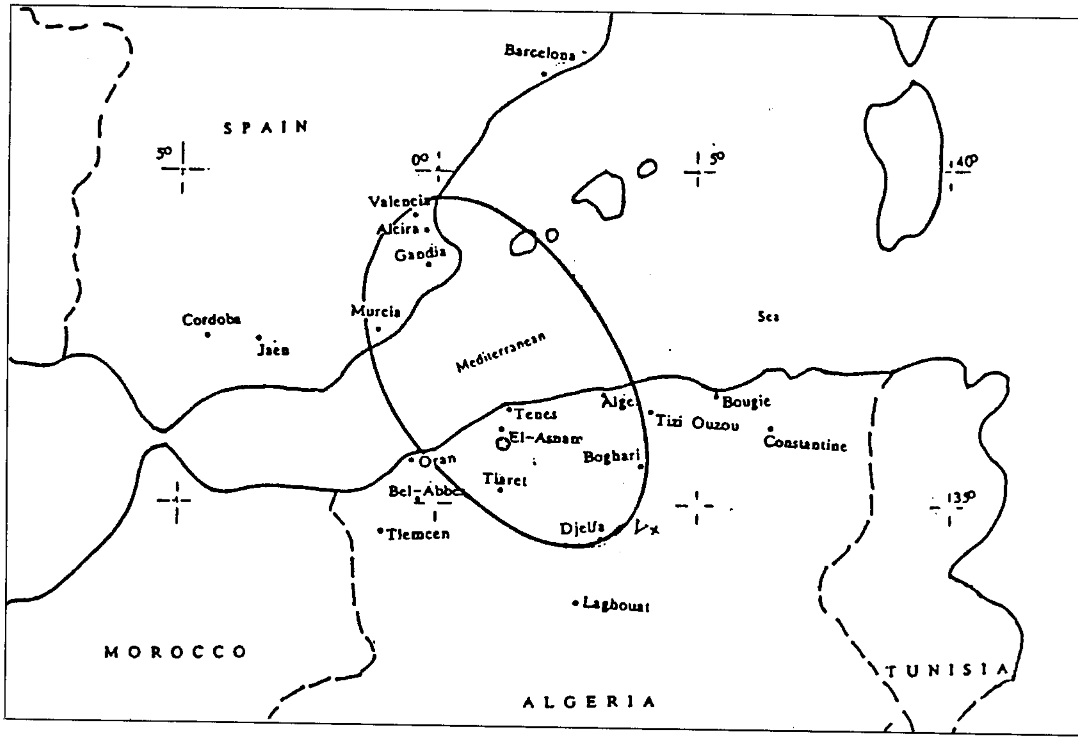


Fig. 3. Map of the affected area (where damage had been observed) of El-Asnam, 10 October 1980 earthquake, showing the approximate zone of intensity V^+ (MSK). The open star shows the macroseismic epicentre of the main shock.

In spite the importance of the earthquake and the abundance of macroseismic data, only few writers have assigned intensities and drawn isoseismal maps. Ambraseys (1981a), from a field visit, has assigned intensities to more than 25 sites in the affected area (fig. 4). Benhallou (1985), from field reports and questionnaires, has published an isoseismal map (fig. 5). Amokrane *et al.* (1981), from a field report, have allocated intensities to several sites and published an isoseismal map (fig. 6). Espinosa *et al.* (1984) have also published an isoseismal map for intensities I = VI (MM) and larger (fig. 7). The Algerian Technical Control of Constructions (CTC, 1981) published an isoseismal map based on field visits and questionnaires (fig. 8). Some other authors and agencies have also allocated different intensities to the epicentral zone. The maximum intensities assigned are: I_0 = IX-X (MSK), (Meneroud *et al.*, 1981); I_0 = X (MSK), (Hoang Trong Pho *et al.*, 1981); I_0 = IX (MSK), (Papastamatiou, 1981); I_0 = X-XI (MM), (Khemici, 1983 in EERI); I_0 = X (MSK), (Mezcua and Martinez, 1983); I_0 = X (MM), (CTC, 1981); I_0 = IX-X (MM), (EERI, 1983). Many other studies were conducted in the fields of tectonics, geology, seismology, geotechnics, engineering, ground motion, damage statistics, modellisation, aftershocks, socio-economic impacts, relief operations,... etc. (Ambraseys, 1981a,b; Benhallou, 1985; Ouyed and Hatzfeld, 1981; Petrovski, 1981; Papasta-

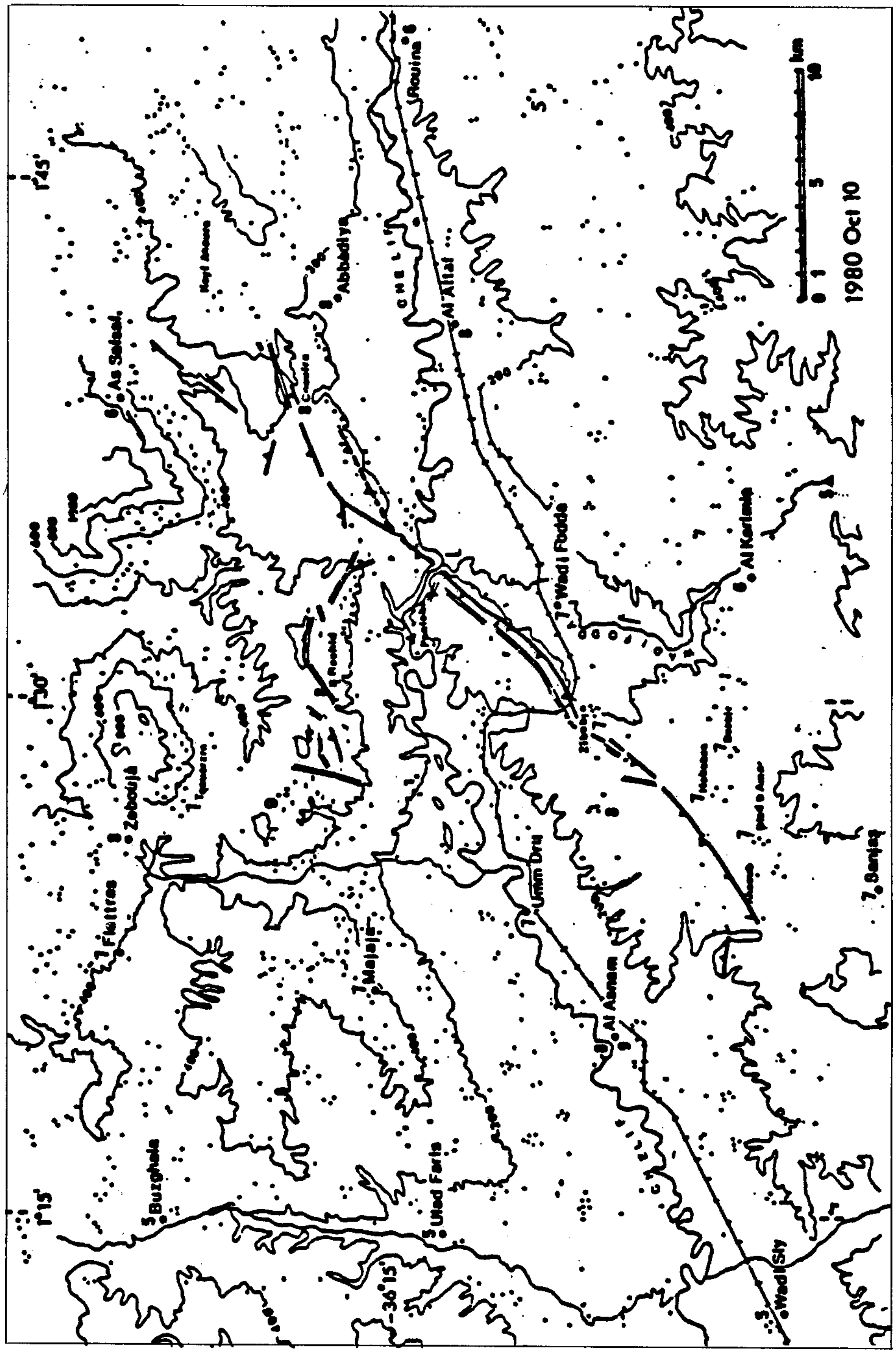


Fig. 4. Intensity distribution, in terms of the MM scale, of the 10 October 1980 El-Asnam earthquake, after Ambraseys (1981a).

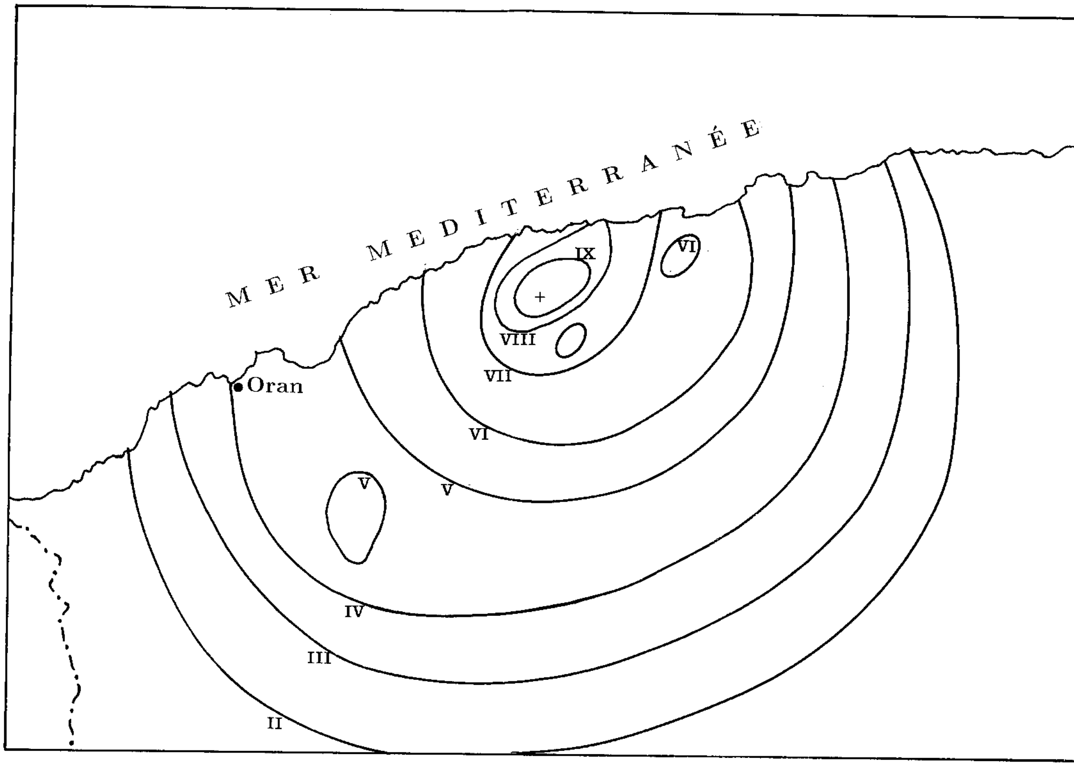


Fig. 5. Isoseismal map, in terms of the MSK scale, of the 10 October 1980 El-Asnam earthquake, after Benhallou (1985). *Redrawn.*

matiou, 1981; Philip and Meghraoui, 1983... etc.).

Instrumental studies were also conducted by several authors and agencies. The epicentral location was given at 36.170°N, 1.415°E (Dorel, 1981); 36.125°N, 1.399°E (Ouyed *et al.*, 1982); 36.159°N, 1.403°E (ISC); 36.143°N, 1.413°E (PDE-USGS); 36.14°N, 1.35°E (CSEM); 36.153°N, 1.446°E (SSIS). Magnitudes for this event were also determined by some authors and stations at MLH = 7.8 (BNS); MLH = 7.4 (ATH, GRF); MLH = 7.2 (HFS, SKO); MLH = 7.1 (TTG, SRO); MLV = 7.5 (STR); MLV = 7.3 (NEIS, VKA, MOX); MLV = 7.2 (SPC, PRU); M_S = 7.3 (USGS, Papastamatiou, 1981); M_S = 7.2, m_b = 6.5 (Ambraseys, 1981a,b); m_b = 6.3 (ISC).

3. Geographical aspects of the epicentral region

The devastated region lies between the two parallel ranges of Dahra and Ouarsenis (Atlas Mountains). The epicentral area is at about 170 km southwest of the capital Alger and on the southern side of the coastal range of Dahra. The Dahra includes in the north a mountainous region where the height is over 1000 metres, the Djebel Bissa is culminant at 1157 metres, the Djebel Sidi Bernous at 1146 metres and the Djebel Tkelout at 1041 metres.

El-Asnam, a modern city because 75 percent of its buildings were built after the 1954 Orleansville earthquake, is the capital of one of the most important granaries in

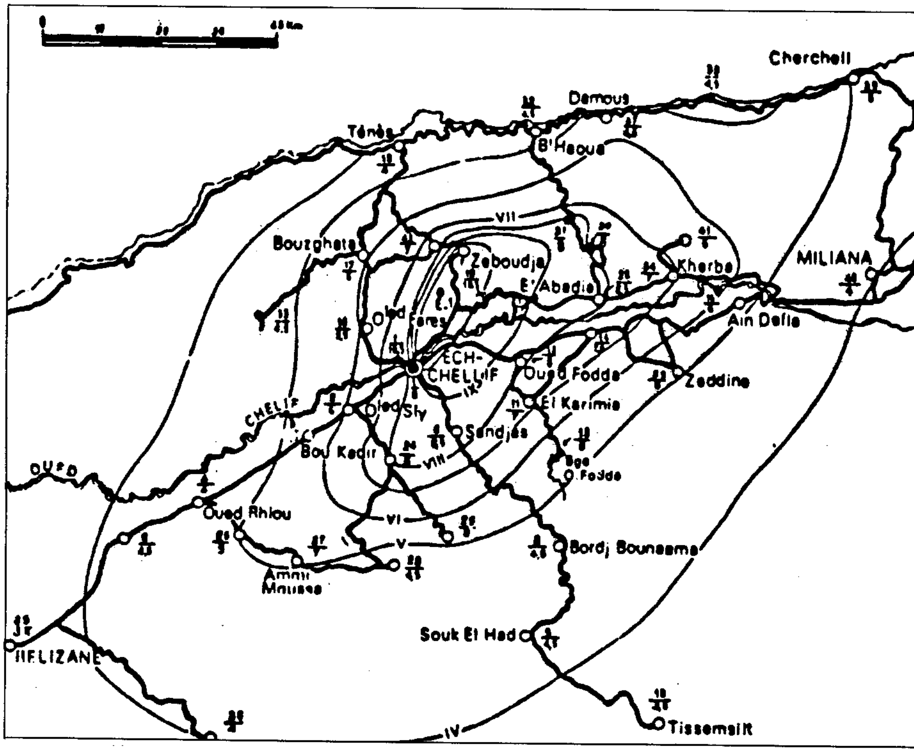


Fig. 6. Isoseismal map, in terms of the MSK scale, of the 10 October 1980 El-Asnam earthquake, after Amokrane *et al.* (1981).

Algeria, the wilaya of El-Asnam. Algeria is organized into 31 Wilayas, regional administrative body. The Wilaya of El-Asnam extends 8675.70 square km, counted 885 200 inhabitants (Census of January 1978), is limited by Medea in the east, Mostaganem in the west, Tiaret in the south and the Mediterranean Sea in the north. It is divided into six Dairas (County or Borough) which count 29 baladias (City or Council). The Daira of El-Asnam which is composed of three Baladias: El-Asnam, Sendjas and Ouled fares with a population of 155 824 inhabitants. The other Dairas are Miliana (107 661 inhabitants), Tenes (120 814 inhabitants), Ain Defla (83 661 inhabitants), Bou kadir (125 163 inhabitants) and El-Attaf (142 143 inhabitants). In 885 200 residents, only 183 134 were living in urban zones.

Since early colonization of Algeria, the French settled in the Cheliff valley and made of it an important farming region (Yacono, 1955). After the independence in 1962, the main objective of the Algerian government, encouraged by the natural resources wealth, was to develop the country through the so-called industrial, cultural and, agrarian revolutions and to promote the level of living standard of the people. In 1962, the El-Asnam Wilaya counted only few small industrial units inherited from the colonial period. By 1980, the same wilaya disposed of three industrial zones located at Oued Sly (west), Ain Defla and Khemis Miliana (east). In the frame of the whole process of development, in 1972, President Houari Boumediene instituted a special programme for the Wilaya

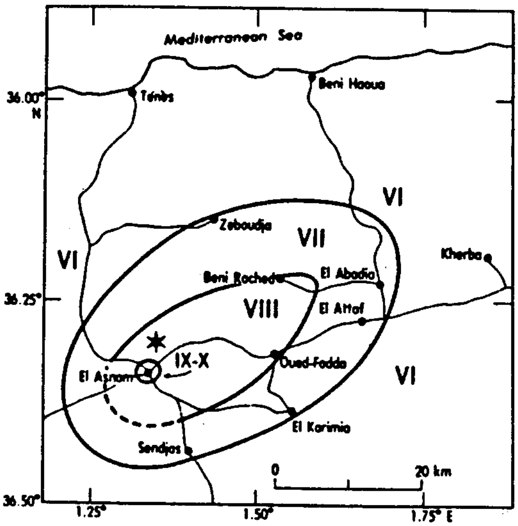


Fig. 7. Isoseismal map, in terms of the MM scale, of the 10 October 1980 El-Asnam earthquake. The star shows the epicentre location of the main shock, after Espinosa *et al.* (1984).

of El-Asnam of an amount of 184 millions of Algerian Dinars (about U.S. $ 45 millions). The hydraulic system programme composed of 120 projects including protection of the banks of Oued Cheliff, constructions of reservoirs and purification stations. To the agricultural sector, half of the investment was allocated to the re-afforestation of the region. For the habitat domain, an important programme of dwelling construction was launched, which was composed of 1000 urban apartments, 2000 suburban dwellings and 5000 rural lodgings. The educational system has profited by the construction of 1450 classrooms and 750 apartments for the primary schools, and 13 colleges (comprehensive schools) and 5 Lycées (high schools).

4. Characteristics of the building stock

Due to its agricultural vocation, the Cheliff valley is mostly a rural residential area (Armature Urbaine, 1987). Apart from the industrial zones, official buildings such as local administrations, apartment blocs, post offices, hospitals, schools, cultural centres, markets and public works, most of the rural housing were the typical native construction which is known as gourbi (described in details previously). The building stock in the affected area, prior to 1980 El-Asnam earthquake, varies between four storey modern constructions to single storey adobe houses; it could be divided, with respect to different historical periods of the region, into the three following categories:

1) traditional native dwelling (predominant in rural areas), numerous constructions that withstood the Orléansville 1954 earthquake and most of which were repaired after the earthquake;
2) constructions built after the 1954 earthquake, except the traditional native gourbi, were generally reinforced concrete structures and masonry constructions;
3) constructions built after 1962, apart from the traditional rural habitat, were reinforced concrete and steel structures.

The constructions of the first category are mainly the traditional unreinforced stone-mud or mud-thatch constructions with heavy roofs (described previously) and some French settler unreinforced masonry houses with tile roofs. This last type of building is generally characterized by thick masonry walls but unfortunately untied which made them very vulnerable to earthquake loads.

The second category consists of generally two way reinforced concrete structures. The floors were hollow precast concrete elements with a 4 to 5 cm thick overtopping of reinforced concrete slab. Exterior and interior walls were generally made of hollow precast concrete infill. This type of construction was mainly used for buildings of one to four storeys. Generally, the constructions were elevated from the ground floor on pilotis, whereas apartment build-

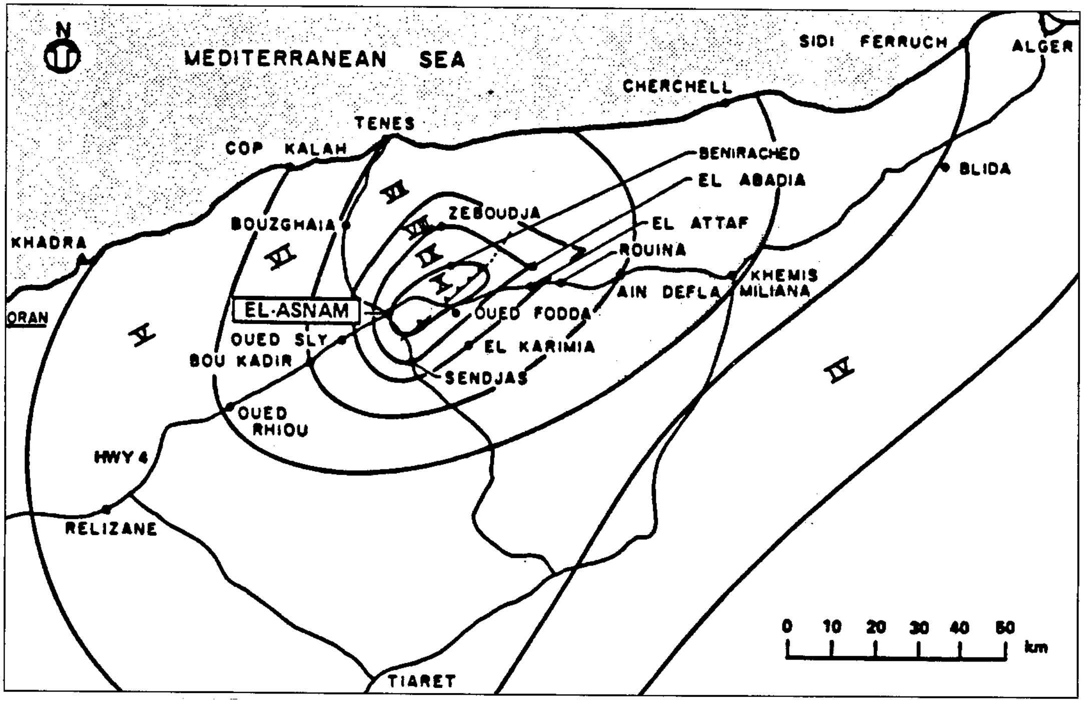


Fig. 8. Isoseismal map, in terms of the MM scale, of the 10 October 1980 El-Asnam earthquake, after CTC (1981).

ings were commonly built on a short crawl space (vide sanitaire), which is used for water, gas, sewage and ventilation conduits, supported by short columns. Most of this type of construction was encountered in the town of El-Asnam.

Constructions classified in the third category are those built from 1962 onwards which represent a small percentage of the total building stock. The Algerians used to the French technology of construction continued, unofficially, building with the French seismic design and construction regulations. Most of these buildings are up to four storeys high with reinforced concrete frames with hollow bricks or concrete panels infill. The vide sanitaire was still encountered in most of the public buildings and apartment blocs. The typical building is two bay wide (7 to 8 m including the corridor) by twelve bay long (about 40 m). Most of these constructions were based on strong beams and weak columns which caused the pancaking collapse of many modern buildings. Floors are constructed with precast reinforced concrete shallow beams supporting hollow precast concrete elements. The floor assembly is covered with a reinforced concrete slab 5 to 6 cm thick. The foundations consist of footings tied with beams 45 to 65 cm deep or a general raft. Expansion and rupture joints are commonly used. In late seventies, reinforced concrete shear walls appeared in many buildings in Northern Algeria.

The building stock of Algeria had numerous variable characteristics such age, materials and structural system. The building types exposed to the shock consisted mainly of structural types A, B and a small percentage of type C structures, as defined by the MSK scale.

5. Damage and casualty distributions

The abundance of information available, provided by numerous sources, describes in details the impact of the earthquake on humans, man-made structures and the ground itself. The immediate consequences of the earthquake are measured in terms of casualty rate and destroyed or irreparably damaged buildings.

El-Asnam, built in the beginning of the Christian era by the Romans under the name of Castellun Tingitatum, was, in this century, partly destroyed in 1922, 1934 and completely devastated in 1954. In 1980, El-Asnam, a modern town of 120000 inhabitants, struck by the 10 October earthquake, was looking as through it had been the victim of a thousand-bombing raid. It is reported that at least 1500 people died, 4000 were injured and 88000 homeless in this town alone. The stories that each one of the survivors had to tell were repetitions in their agreement. The earthquakes (main and early aftershocks) terrified the inhabitants exceedingly, great indeed was their consternation. The atmosphere in the city, after the shaking, was insupportable as reported. Many victims were trapped under the debris of concrete structures that remarkably collapsed without any resistance to the earthquake. The screaming of men, women and, children and, the sound of sirens and ambulances turned the region into a veritable inferno. No term is adequate to describe the extent of the tragedy. Witnesses reported that the ground movement, in El-Asnam and further north-east, started with a violent vertical shaking followed by a long series of horizontal movements of small frequency and less intensity. Equilibrium was affected by many people; like a drunken man, people staggered as they stood. In few seconds, thousands of families were so cruelly separated, many children became orphans and, numerous fathers and mothers found themselves without families. We noticed that the earthquake, not only destroyed the constructions, but also, devastated the social structure and the socio-administrative organization of the region. The main shock and its largest aftershock caused extensive damage to the city of El-Asnam; they destroyed numerous buildings including modern engineered structures as Hotel Cheliff, the cite An-Nasr (apartment-market-restaurants), the police station, city hall, palace of justice, the main hospital, fire brigade station, state prison, schools and a new medical clinic. All the lifeline system was disrupted. According to CTC (Algerian Technical Control of Constructions), the earthquake completely destroyed at least 20 percent of the building stock in El-Asnam, seriously damaged another 60 percent and slightly damaged the remaining. It is estimated that 80 percent of the building stock of El-Asnam was irreparably destroyed. It was reported that many modern structures had suffered pancake collapse in which hundreds of people perished under the rubble. The most impressive structural failure, in terms of extent of damage, lives lost and size of buildings, is the cite An-Nasr. A large construction (100 × 100 m), that contained more than 3000 inhabitants, was built in 1956, according to the French seismic design regulations AS 55, on the site of the late Hotel Beaudouin destroyed totally during the 1954 Orléansville earthquake. This mixed housing-market-restaurant complex, in the centre of El-Asnam, presented an apocalyptic vision. It completely collapsed apart one corner building and part of the Mosque precariously survived. The buildings were reduced to dust and torn into pieces; the slabs of the floors were pancake superposed. It was reported that more than 1000 people were killed in this building complex. The main hospital completely destroyed became a large grave for the patients, as reported. A new medical clinic, just completed but not yet in service, failed completely. The 3 storey Hotel Cheliff, built in 1959 by the French, according to the AS 55, experienced also a pancake collapse. The hotel was no more than a huge concrete slab, crevassed in numerous places. It was said that the restaurant, at the time of the shaking, was full and that 300 to 400 people were in the premises of the hotel. Seventy percent of the school building stock collapsed or experienced sufficient damage to be demolished. The sports centre (CREPS) was reduced to a lump of entangled concrete and steel. The majority of commercial buildings failed or sustained enough structural damage to require demolition. Some constructions appeared intact, from the exterior, were completely ravaged inside. This earthquake destroyed all lifeline systems in El-Asnam which needed months to be restored. Most of the very important projects such as the industrial zone, the bridges, the dams and the reservoirs sustained relatively slight damage. Around El-Asnam, damage was reported to secondary hydraulic works as elevated canals, galleries and the main pipe system. The road system was seriously affected by the earthquake within a radius of about 40 km from the centre of El-Asnam.

The earthquake was associated with surface faulting. The closest distance of El-Asnam to the surface fault trace was at about 8 km. Soil liquefaction had been observed in the flood plain of Oued Cheliff (fig. 9). In El-Asnam, no direct causes leading to structural damage were imputed to liquefaction or landslides.

At 800 m from the centre of El-Asnam, Bouquaa Sahnoun a residential complex, still under construction during the shaking, was almost completely destroyed. A witness reported saying that: «... I was lying on my bed when at 13 h 30 min (local time), a strong explosion followed by a rumbling coming from the earth awaken me up. I tried to flee but I had fallen three times on the floor before I reached the street. This had a duration of few seconds. When out in the streets, it was an horror. A cloud of red dust was in the air, the rumbling continued and before my eyes the buildings were collapsing as in nightmare. I could not keep my full equilibrium...». No dead were reported but many people were injured and at least 100 houses collapsed. Nearby, Bouquaa Salma where tens of villas were just completed, but not yet occupied, were destroyed.

In the surrounding villages and douars, where so much daily life generally takes place in the gardens, few people were reported killed in spite of the heavily damaged or totally destroyed dwellings. Northeast of El-Asnam at about 25 km, the village of Beni Rached located up on the Dahra mountain experienced heavy damage. It is reported that more 15000 people were made homeless. The ground was seriously cracked in several places. The village was crossed by a huge crevasse long of tens of kilometres and wide from 50 cm to several metres. The earthquake triggered massive landslides and rockfall which demolished several douars and blocked many roads in the region. A normal fault scarp near the village was observed. Soil liquefaction was observed in the Beni-Rached area. The houses in this region were generally adobe (gourbi type) or masonry dwelling with tile roofs. Apart where the ground rupture occurred on the site of the construction, damage was scattered and not severe. It was unusual to find a building that had not been destroyed by ground rupture virtually undamaged. Total collapse of buildings was rarely reported but cracks in masonry walls, displaced or fallen roof tiles, removed stones from adobe walls were very common. Several mud-stone houses and adobe dwellings (gourbis) that were either on the fault or within 50 m of the fault collapsed. In the other hand, few houses and a Mosque, relatively well built with unreinforced masonry or local adobe with tile or thatched roofs, experienced slight damage although they were within 50 m of the fault trace.

Sendjas, a small village at approximately 12 km south of El-Asnam, was, as re-

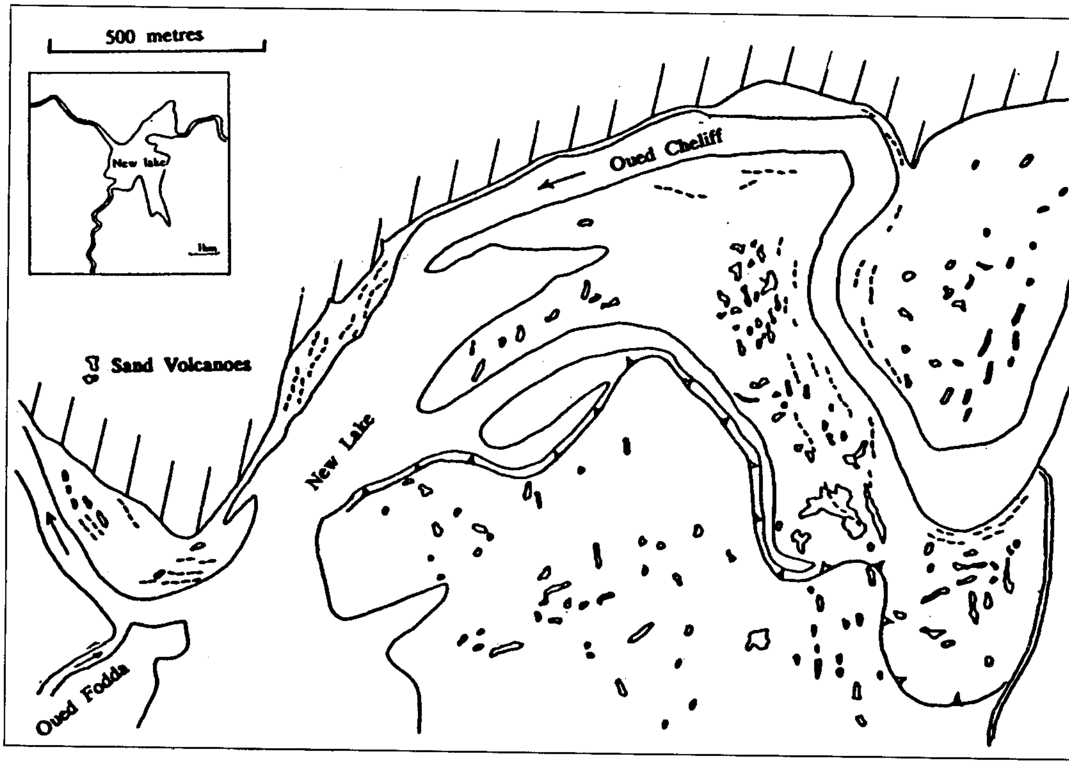


Fig. 9. Map showing surface features left behind the earthquake in the flooded Oued Chelif plain, based on aerial photo taken on November 1981 by INC (Algeria), after Meneroud *et al.* (1981).

ported, 100 percent destroyed and one of the most affected. It formed with El-Karimia the southern limit of major damage. People, in general panic, had to flee from their homes and camped in the open field, far from the constructions which still were threatening of collapsing. The whole village was reduced to lumps of stones, mud, thatch, concrete and steel mixed up. The Mosque and, the old and new post offices were destroyed completely. It was reported that more 150 people had lost their lives, other 420 injured and at least 22000 were homeless. Sendjas sustained so much damage and casualties that the authorities installed a hospital (soviet donation) in the premises. From a press interview report with Soviet medical doctors, it was said that at least 4700 injured were nursed in the hospital. Thirty km east of El-Asnam, the village of El-Abadia and its depending douars where 7000 people were living sustained heavy damage. Most major buildings were partially or totally down to the ground. The gendarmerie, the post office and the cultural centre were no more than a big lump of concrete and steel entangled. In the main street Aoumer Mohamed, collapse was so complete that there was no mean to determine exactly how these constructions looked like. The surrounding walls of the stadium were scattered on the ground. The old town clock which survived the 1934 and 1954 earthquakes collapsed entirely. At the depending douars the situation was more tragic. All the constructions, generally adobe or simple masonry houses, collapsed making several thousands of people homeless. The lifeline systems of the region were all cut-disrupted. The hilly country roads were either blocked or damaged by landslides and rockfall; the relief teams could find no other mean to reach the sinestered douars than helicopters. Soil liquefaction was particularly reported in and around this village. It was reported that more than 500 people were killed. There was no report of the number of injured and homeless.

El-Amria with its depending douars, an agglomeration of 9000 people, had had 90 percent of its constructions razed to the ground. The post office and the cultural centre were irreparably damaged. Tacheta, 10 km northeast of El-Abadia, presented the same scenes as El-Abadia and Beni Rached. Reports on damage and casualties among the population were rare. East of El-Asnam at about thirty kilometres, El-Attaf and its depending douars with 7500 inhabitants suffered heavy damage and casualties. The damage was variable, many old and modern constructions collapsed, others cracked as few survived. The population panicked, fled from their homes and camped in the open field. It was reported that 70 percent (282 classrooms) of the school building stock, two Mosques, the Daira hall and, the post office were completely destroyed and, the cultural centre and the telephone relay were significantly damaged (35%). Reports said that the earthquake had caused the loss of 650 lives, injuring more than 2100 and making at least 15000 homeless. Soil liquefaction was also observed in this agglomeration. The same degree of shaking, or even more, was experienced at Oued Fodda, a locality of 11000 inhabitants, at about 18 km east of El-Asnam. This area was hard hit; here, many more buildings collapsed than in El-Attaf. The college (CEM), the grain storage silos (OAIC), the cinema, the gendarmerie, the cultural centre and several other buildings were down to the ground. The ground surface was cracked in almost every direction. The manifestation of the earthquake itself was a visible surface fault passing very close to the village. It was at about 3 km west of Oued Fodda, where the fault cut the Alger – El-Asnam railway line and the Oued Cheliff bed. The uplifting of the north-west of the fault formed a dam on Oued Cheliff and a lake upstream of the dam. Soil liquefaction was observed in and around Oued Fodda. Among the most impressive sights left behind the earthquake were the bending of the railway lines and the uplifting and overturning of the freight train that was crossing the fault at the moment the shaking occurred. Fortunately, the driver of the train was met and reported what he had felt and experienced. He reported as saying that: «The shaking occurred at the time the train was crossing the fault at a speed of 60 km/h. The locomotive was uplifted from the railway and then abruptly fell again. The brutal shock had triggered the automatic brakes. I was projected up from my seat as my head knocked the roof of the cabin. When falling back, I felt the ground moving laterally toward the south direction. During this short time, many carriages were already tipped over and then the locomotive overturned to the left and ended resting on its side...».

El-Karimia, lying between the village of Oued Fodda and Oued Fodda Dam, had experienced some significant damage. Most of the concrete and masonry buildings sustained major damage while adobe and mud-stones houses suffered much more damage such as total destruction and fall of many walls. In some places, cracks in roads and change in flow of springs were observed. The newly built post office was totally destroyed. This village with Sendjas formed the southern limit of damage. Oum Drou, a small village at about 5 km east northeast of El-Asnam, was presenting the same spectacle as the villages of Oued Fodda and El-Abadia. It was reported that 29 percent of the buildings suffered total collapse, 47 percent seriously affected and

21 percent sustained slight or no damage. The six concrete filling panels of the water tower were thrown away. The Oum Drou Dam, 10 km of the epicentre, sustained slight damage (cracks) in certain parts of the structure. The small village of Zeboudja, which is at 20 km north of El-Asnam, and its depending 29 douars were completely destroyed. Underground water pipes were cut and uplifted. It was reported that liquefaction and significant landslides were observed. The village of Bou Kadir, 20 km south-east of El-Asnam, sustained significant damage. In this village at least 25 percent (75 classrooms) of the school buildings suffered total destruction and the cultural centre seriously damaged (30%). As reported, 44 people had lost their lives, 72 were injured and 16000 homeless. There was at least 2200 housing units destroyed or irreparably damaged.

In the northern coastal town of Tenes, 40 km north of El-Asnam, serious damage was not observed in the city itself but was considerable in the surrounding douars. Five percent (22 classrooms) of the school buildings, the post office and one Mosque sustained complete failure. Three other Mosques in the Daira of Tenes suffered moderate damage (20 to 50%). The shaking was so strongly felt that people had to flee from their homes and camp in the open field. It was reported that in this baladia, the earthquake caused the loss of 36 lives, injuring at least 262 and making around 15000 homeless; it destroyed or badly damaged at least 2000 housing units (gourbis).

In Rouina, 12 km southeast of El-Abadia and 13 km east of El-Attaf, only damage to property was reported. No casualty was declared. Here, the vertical shaking was less intense than in the epicentral zone, the main movement was a horizontal east-west oscillation. This was enough to make people loose their equilibrium and fall over to the east. One account said that people in cars stopped as their cars were going left and right during the shaking.

Ain Defla, at about 55 km east of the epicentral zone, sustained moderate to heavy damage. One account said that, at 13 h 30 min (local time), an explosion and a rumbling covered the region and put all the population in general panic. The shaking was so strong that the people had to flee from their homes; the patients of the hospital were also evacuated to the open field. Some relatively well built reinforced concrete buildings as the cultural centre, the hospital and many other buildings were very much cracked. Twenty percent (86 classrooms) of the school buildings, the city hall and the post office were destroyed. Isolated houses, as much as 600, were completely destroyed or seriously damaged. Cracks in walls and fall of plaster were observed in many other buildings. Roads were also cracked in several places. It was reported that 49 people had lost their lives. The distribution of damage in the wilaya of El-Asnam is summarized in Table II. At about 60 km east of El-Asnam, Khemis Miliana was the last town where damage could be clearly observed. The shaking was felt by all the people either inside or outside the buildings. The constructions were strongly shaken so they sustained considerable damage. Three percent (16 classrooms) of the school buildings were destroyed and one Lycée was partially damaged. Nearby, Hammam Righa (hot spring), a small village up on the mountain, was seriously shaken. It was reported that the shaking, preceded by an explosion and a deafening rumbling, was so strong that the people had to flee from the hotels and their homes to the open fields. The main hotel of Hammam Righa, built with sand and stones in the Roman era, was destroyed and trapped several customers under the rubble in the basement. The relief teams could not reach the site before several hours because the roads were blocked by the earthquake-induced landslides and rockfall. Considerable damage was observed in Cherchell and Miliana but reports of details are rather rare.

At the capital Alger, 170 km east of the epicentral zone, the shaking was strong enough to make people flee from their

Table II. Distribution of damage in the wilaya of El-Asnam, after CTC (1981).

Daira	Village	Dist. from fault (km)	% Totally destr. buildings
El-Asnam	El-Asnam City	10	65.3
	Ouled Fares	20	29.2
	Chetia		21.4
	Oum Drou	8	75.0
	Sidi Ben Ali		22.2
Ain Defla	Ain Defla	27	43.0
	Rouina	17	63.4
	Arib	32	57.1
	Djelida	43	73.3
Tenes	Abou El Hassan	39	33.3
	Bouzghaia	30	27.8
	Zeboudja	18	42.1
	Sidi Akacha	35	28.6
Boukadir	Ouled Ben AEK	0.5	77.8
	Boukadir	10	41.0
	Ain Merane	26	40.0
	Oued Sly	11	40.4
El Attaf	El Attaf	8	68.6
	El Abadia	6	84.2
	El Karimia	7	64.0
	Oued Fodda	0.7	64.8
	Beni Rached	4	58.7
	Bir Safsaf	0.5	71.4

homes particularly in high rise buildings and the Casbah. 16 buildings of the Casbah, seriously cracked and threatening of collapse, were evacuated. In whole afternoon, a general panic reigned in the streets of the capital and its surroundings. Account reported that the population felt the ground waving and rumbling. Some people were injured when fleeing the Mosques. Across the bay of Alger at Bordj-El-Bahri, it was reported that widespread physical symptoms were observed. These included giddiness, nausea, vomiting, debility, trembling knees, and pain in the knees and legs. Because the shocks were less frequent, people were apt to attribute their symptoms to other causes than the earthquake. Since it was lunch time, many people imputed their sick feeling to the food they were eating. Physical symptoms were accompanied by psychological disorientation.

The shaking caused panic at Alger, Blida, Tiaret, Frenda and Mostaganem but no damage was reported. People at rest in the towns of Bejaia, Laghouat and Tlemcen had felt the tremor.

In Spain, the earthquake had caused

panic movements, at certain places as Murcia, Gandia, Alcira and Valencia, and slight damage but no fissuration. The shock was perceptible as far as Cordoba and Barcelona, 570 km north of the epicentre, but it was not felt in Morocco (Ambraseys, 1981a and Press Reports, 1980).

6. Intensity re-evaluation

All the data retrieved from the various sources of information available to us, were analyzed and used in the re-evaluation of intensities with reference to the Medvedev-Sponheuer-Karnik (MSK) scale.

Maximum intensity I_0 = IX (MSK) was assigned to a number of villages along the Cheliff valley. The area of greatest structural damage and loss of life is confined within the narrow zone between Sendjas, Zeboudja, El-Abadia and El-Asnam. Broadly, this signify that within the area that contains most of the ground features associated with the earthquake, adobe houses were totally destroyed and, masonry and reinforced concrete structures collapsed or were seriously damaged causing significant casualties. Intensity VIII was attributed to the villages as Ain Defla, Rouina, El-Karimia, Oued Sly and Ouled fares. Intensity VII was allocated to villages as Boukadir, Tenes, Khemis Miliana, Cherchell and Hammam Righa. Intensity VI was assigned to villages as Tipaza, Medea and Oued Rhiou. Intensity V was assigned to Alger, Saida, Blida, Djelfa, Relizane, Tiaret, Mostaganem and, in spain, to the cities of Murcie, Alcira, Gandia and Valencia. These lower intensities V to VIII are coherent with a rigid interpretation of the MSK-64 seismic intensity scale (Medvedev *et al.*, 1981). Intensity IV was allocated to villages as Rouiba, Tizi Ouzou, Bel Abbes, Aflou and Oran. Intensity III were attributed to the sites as Bougie, Laghouat and, Tlemcen in Algeria and, in Spain, to Cordoba and Barcelona. Most of the low intensities III to IV were assigned only on felt effects and on the lack of any damage to adobe types of construction. For the very low intensities II to III which we could not separate, negative reports were also considered. As a result of the analysis of the macroseismic data, an isoseismal map of the El-Asnam 10 October 1980 earthquake has been drawn and is shown in fig. 10.

7. Magnitudes determination

The surface-wave magnitude of the earthquake was calculated from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period from 35 seismograph stations located at distances between 15° and 138°, and a preliminary epicentre at 36.148°N, 1.438°E. The data are presented in Benouar (1993). The mean period is 16.4 s and the derived value of M_S, without station corrections, is 7.4 (± 0.3).

8. Foreshocks and aftershocks

The earthquake was followed by a long sequence of aftershocks for several months. Some of these aftershocks were strong enough to cause more casualties and damage. According to Hoang Trong Pho *et al.*(1981), during the period 15 November 1980 to 28 February 1981, 5600 aftershocks were recorded. The most important aftershocks, with re-calculated surface-wave magnitudes equal or larger than 5.0, are given on table I. The largest aftershock occurred three hours after the main shock at 15 h 39 min 9 s. This aftershock, not only, interrupted the relief operations but added considerable damage and increased the casualty toll. It was widely recorded; the teleseismic data is used to re-calculate the surface-wave magnitude from 30 seismographic stations located at distances between 15° and 126°, that gives M_S = 6.2 (± 0.3), the details of the data are given in Benouar (1993). The most indicative aftershock is that of 8 November 1980, a sur-

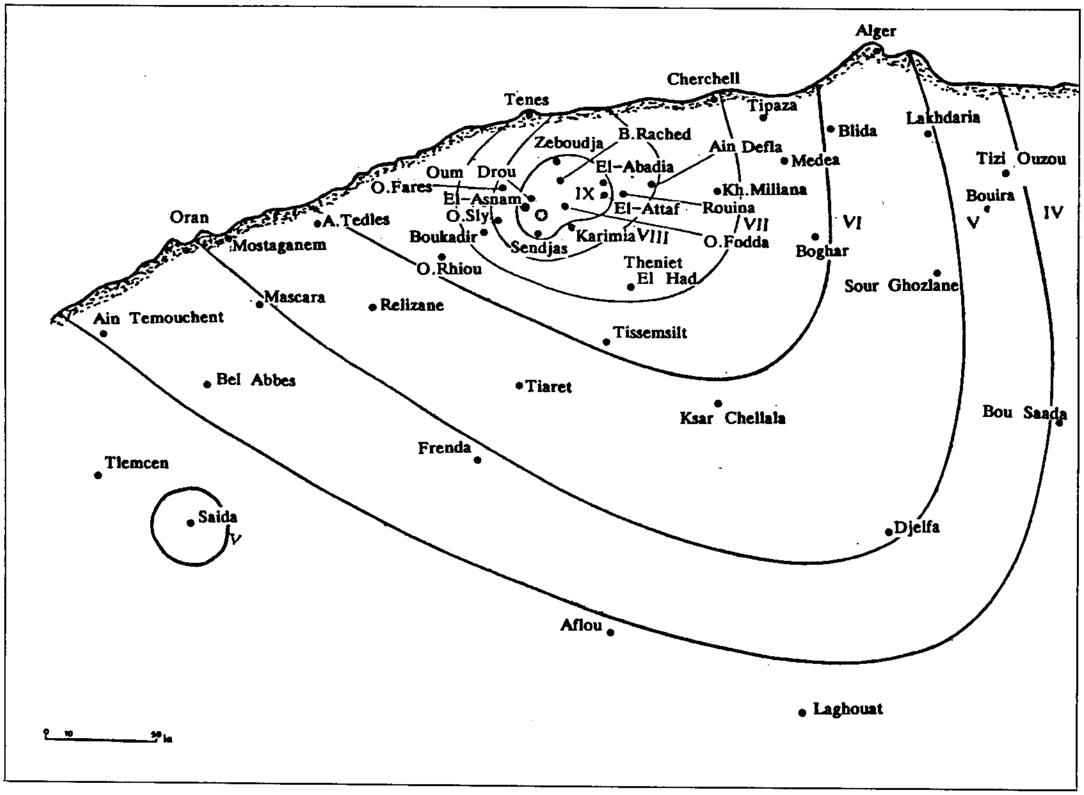


Fig. 10. Isoseismal map of the 10 October 1980 El-Asnam earthquake in terms of the MSK scale. The open star shows the location of the macroseismic epicentre.

face-wave magnitude 5.0 event, for which the strong ground motion was recorded. These accelerograms show that the vertical component of acceleration was predominant with a maximum of 0.31 g and the largest horizontal acceleration was about 0.21 g.

9. Discussion

The Cheliff Valley has already experienced two large earthquakes during this century: Carnot on 7 September 1934 and Orleansville on 9 September 1954. The affected region is well known to be a rich farming area and El-Asnam an important agricultural trading centre. At the time of the earthquake, the wilaya of El-Asnam counted about 900000 inhabitants in which only 183134 (20 %) were living in urban zones. The housing rate of occupancy was about 7 in the cities and 7.7 in the country side. The officially declared casualties, which should be taken with great care, are 3000 killed, 8500 injured and 400000 homeless. Thus, the rate of fatalities caused by the main shock and its aftershocks vary from place to place with a maximum of 1.25 percent in El-Asnam. The average rate of the whole affected area is 0.34 percent. The number of injured was reported to be 8500 which represents an average rate for the area of 0.95 percent. Other sources reported that authorities had announced 4318 dead and 9870 injured. As it was reported, according to health authorities, that at least 6000 were killed and more than 60000 injured in which 3000 were seriously.

According to the sources of information available, the El-Asnam 1980 earthquake is the first event associated with large surface rupture in the Maghreb region. The main shock and its strong aftershocks caused widespread damage associated mainly with the high vulnerability of certain types of constructions. From the isoseismal map, it can be noted that large intensities of shaking had attenuated rapidly to the west and south of the fault-break but expanded more to the east where it caused damage as far as Alger.

As in past destructive earthquakes in Algeria, constructions built with adobe and unreinforced masonry suffered considerable damage or total collapse. This earthquake had shown that even modern engineered buildings, in Algeria, can be highly vulnerable without the enforcement of aseismic building rules. The damage was widespread in the villages and douars, close to the epicentre, on both sides of the Oued Fodda fault. The great toll of life loss associated with this earthquake is due to the total failure of various types of structures and the high rate of occupancy of the buildings. The reasons of the extended damage experienced by the buildings of El-Asnam and its surroundings are particularly: the use of brittle construction materials, inadequate design to resist earthquakes and, detailing due to lack of a national building code and in numerous cases deficiency in workmanship and control. Some buildings were designed to resist earthquakes loads, as the cement plant in El-Asnam, survived without any significant damage.

Although, most damage and casualties, reported by numerous sources, were due to the main shock, the possibility of cumulative damage remains from the earlier strong aftershocks and particularly the largest of 10 October 1980 at 15 h 39 min 9 s (GMT).

One of the conclusions that can be drawn from this earthquake is the ease with which the Algerian buildings and other facilities were damaged. Wether it is modern constructions or gourbis, the buildings are potentially vulnerable to the recurrence of destructive earthquakes, particularly, in the rural zones.

In Algeria, before 1980 earthquake, the seismic hazard was not appearing as a threat to the country in terms of casualty rate or economic disturbances. This earthquake suddenly alerted the Algerian authorities to the high seismic hazard that existed and the need of loss-reduction measures to be taken to mitigate the potential losses in future earthquakes. The analysis of the impacts of the destructive earthquakes that occurred in Algeria has shown that the scope of the disaster could be reduced with a great amount if appropriate measures were taken. A brief summary of loss-reduction measures taken by the authorities is given in Appendix 1 of this earthquake report.

Summarizing the results, the following data for the 10 October 1980 earthquake are obtained: origin time (GMT) 12 h 25 min 23 s; instrumental epicentre at 36.143°N, 1.413°E (PDE-USGS); macroseismic epicentre at 36.148°N, 1.438°E; focal depth of about 10 km; magnitude $M_S = 7.4$ (± 0.3).

APPENDIX 1. Governmental measures in mitigating the impact of earthquakes in Algeria.

Prior to the 1980 El-Asnam earthquake, the seismic phenomena was not appearing as a threat neither to the Government nor to the population. It is that earthquake that suddenly alerted the Algerian authorities to the high seismic hazard that existed in the northern part of the country where more than 90% of its socio-economic installations are concentrated. The extent of the social and economic impacts of the El-Asnam earthquake has given a proof that appropriate loss-reduction measures should be taken to mitigate the potential losses in future earthquakes.
Following the 1980 earthquake, numerous measures have been taken by the Algerian government to mitigate the seismic risk. The most important measures are summarized as follows:

- 1980: the CRAAG (National Research Centre of Astronomy, Astrophysics and Geophysics) has been charged with the management of the Algerian seismological network;
- 1981: appearance of the first Aseismic Code for Building Design and Construction (RPA 81);
- 1982: the Arab Ministers of Construction in their June 1982 meeting, in Algiers, recommended a programme for the evaluation and reduction of the seismic risk in the Arab world (PAMERAR) with the cooperation of the UN specialized agencies;
- 1983: appearance of a new version of the Aseismic Code for Building Design and Construction (RPA 83);
- 1984: completion of the seismic microzoning of the El-Asnam region;
- 1985: the Algerian parliament adopted the law 85-231 of August 25, 1985 which established a disaster relief organization;
- 1985: appearance of the First Recommendations for Strengthening, Reinforcement and Repair of Damaged Constructions by Earthquakes;
- 1985: creation of the National Centre for Applied Research in Earthquake Engineering (CGS);
- 1985: a Telemetric Seismological Network was attributed to CRAAG to survey all Northern Algeria;
- 1985: the Ministry of Construction has created a governmental permanent commission to update the regulations for earthquake resistant-design;
- 1988: appearance of an updated version of the Aseismic Code for Building Design and Construction (RPA 88);
- 1988: participation of Algeria to the Programme of Seismic Risk Reduction in the Mediterranean Region (SEISMED);
- 1990: the CRAAG has been put under the supervision of the Ministry of Interior by decree of April 17, 1990;
- 1990: participation of Algeria to the International Decade for Natural Disaster Reduction (IDNDR) programme;
- 1981 to 1990: several seminars, conferences, training courses and worshops have taken place for education and technology transfer to the Algerian scientists, engineers and planners;
- 1990 to 1993: re-evaluation of the seismicity of Algeria and adjacent regions during the twentieth century in the frame of a PhD thesis (this work) under the supervision of Professor N.N. Ambraseys at Imperial College.

The Constantine earthquake of 27 October 1985

Abstract
This research examines one of the largest earthquakes in eastern Tell Atlas in this century. The Constantine earthquake, which occurred at 19 h 34 min 56 s (GMT) on 27 October 1985, has been the strongest recorded event in the Tell Atlas since El-Asnam 1980 earthquake and in Constantine region since the beginning of this century. The main shock was preceded by two foreshocks and followed by a long sequence of aftershocks. The main shock and its early aftershocks caused heavy damage to region comprised between El Khroub, Constantine and Beni Yakoub. The village of El Aria, which suffered most, was the centre of the zone the most affected. This earthquake destroyed several old houses (gourbis), killing about 5 people and injuring over 300. Maximum intensity reached VIII in the MSK scale and covers an area of approximately 8 km radius. The main shock was felt in a relatively small area with intensity III (MSK), as far south as Batna, east as Setif, north as the coast and west as El Kala, about 45000 square km. The earthquake was associated with surface breaks about 4.5 km long, in echelon pattern, in northern part of El Aria and Beni Yakoub, corresponding to a left lateral strike-slip motion. The macroseismic epicentre has been located northeast of El Aria at 36.339°N, 6.924°E. The surface-wave magnitude was calculated, without station corrections, at $M_S = 5.70$ ($\pm$ 0.27).

1. Introduction

On the 27 October 1985 at 19 h 34 min 56 s (GMT), an earthquake caused widespread destruction in Southeast Constantine. The 1985 Constantine earthquake is one of the most significant seismic events in Eastern Algeria, not only because of its size, but also because of its occurrence in one of the most densely populated parts of the country, more than 300 inhabitant per square km (Armature Urbaine 1987, 1988). In terms of the seismic history of Eastern Algeria reported by Hée (1933 and 1950), Rothé (1950), Grandjean (1954), Roussel (1973), Mezcua and Martinez (1983) and recently Benhallou (1985), it was by no means an unattended earthquake. Besides this earthquake, two destructive seismic events occurred in the same region in 1908 and 1947; they claimed similar casualty (about 10 people killed and hundreds of injured) and damage. The population of Constantine had known the same distress during these earthquakes, they fled from their homes looking for a safe shelter in the public gardens and the surrounding woods. These three seismic events give a return period of 39 years for a short time period of observation (this century). By its size the 1985 Constantine earthquake has constituted the largest recorded seismic event in the Tell Atlas since El-Asnam 1980 earthquake and in Constantine region since the beginning of this century. The main shock was widely recorded by most of the seismological stations in the world (474 stations, ISC) at distances varying from 2.64° (Kechata, Tunisia) to 151.84° (Taravao, Tahiti) away.

This event occurred very near where the earlier shocks of 4 August 1908 and 6 August 1947 caused casualty and damage. The main shock was felt, in a relatively small area of about 120 km radius, as far east as El Kala, west as Setif, south as Batna and north as the coast with intensity III^{+} in the MSK scale. The earthquake caused the loss of about 5 lives and injuring at least 300; it destroyed several old houses. The details of the damage and casualty were not officially communicated. Most damage and casualty were observed in the zone comprised between El Khroub, Constantine and Beni Yakoub where the village of El Aria was the centre with intensity VIII (MSK). The earthquake caused serious to slight damage in the zone contained between Ain Fakroun, Skikda, Chelghoum laid and Guelma with intensity V^{+}. Although most of the constructions in Constantine and, surrounding villages and douars sustained important damage as destruction of old houses, cracks in reinforced concrete shear walls, masonry infill walls and, fall of ceilings and plaster, the modern buildings recently built did not suffer any significant structural damage.

The earthquake was preceded by two foreshocks and followed by a long sequence of aftershocks, continuing until the end of November 1985.

The 1985 earthquake was also associated with significant ground deformations, about 4.5 km long ground surface ruptures, in the very close surroundings of El Aria (between Kef Tassenga and Koudiat Ben Ghorara) and Beni Yakoub. Besides the fissures, landslides were also observed in Aioun-Dardar.

2. Sources of information

A complete search, for documents relative to the 1985 Constantine earthquake, was carried out in Algeria and England. The macroseismic data extracted from the different sources have greatly contributed to the reconstruction of this important seismic event. But despite its significance, however, there are surprisingly few reports which have been published up to now. The most important source of information is the work of Bounif (1990). From a field work, Bounif *et al.* have published in 1987 a study on the surface ruptures and aftershocks. Bounif's work, a Magister thesis (M.Sc), is based mainly on his own field observations, University of Constantine (Institute of Earth Sciences) and CRAAG field reports. He assigned in 1987 a maximum intensity VIII-IX (MSK) to the zone between El Khroub and Beni Yakoub. However, in his thesis (1990), he revised his work and attributed maximum VIII (MSK) to El Aria and its surroundings and published an isoseismal map (fig. 1). The engineers of CTC (Controle Technique de Constructions) have visited the affected zone during the period 30 to 31 October 1985 and summarized the damage caused by the earthquake in an internal mission report. It was thought that the documentation on this earthquake would be abundant, particularly, in the Algerian press. Unfortunately, this was not true; all the Algerian press reported the event but with a tiny and general information.

The 1985 Constantine earthquake was recorded by 474 seismological stations (ISC, 1985). Instrumental epicentre locations were calculated at 36.3°N, 6.9°E (LDG); 36.5°N, 6.8°E (NEIC); 36.33°N, 6.59°E (MOS); 36.38°N, 6.71°E (CSEM); 36.43°N, 6.78°E (ISC) and 36.566°N, 7.083°E (CRAAG). The magnitudes were also calculated at $M_L = 5.2$ (LDG); $m_b = 5.5$, $M_S = 5.9$ (NEIC); $m_b = 5.8$, $M_S = 5.8$ (MOS); $m_b = 6.0$, $M_S = 6.0$ (PEK); $m_b = 5.4$, $M_S = 5.9$ (ISC); $M_S = 6.0$ (CSEM) and $M = 6.0$ (CRAAG).

3. Damage and casualty distributions

The macroseismic data retrieved, from the various sources available, have substantially contributed in the re-assessment of the effects of the earthquake. Compilation

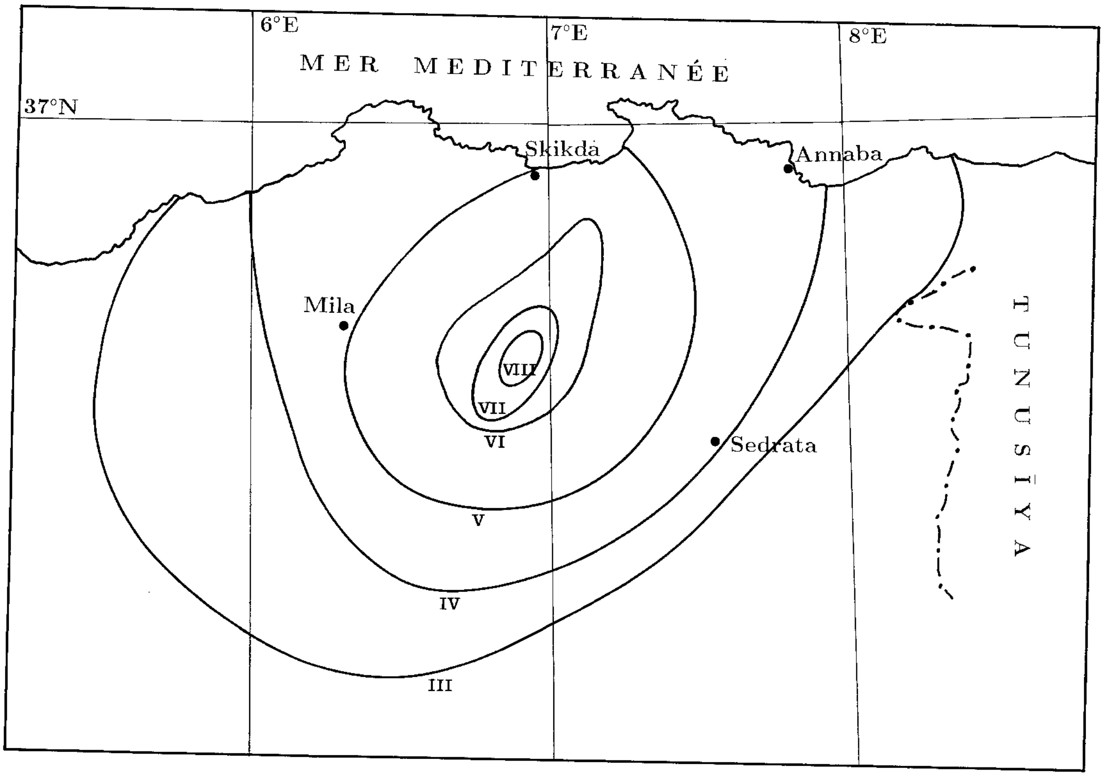


Fig. 1. Isoseismal map (in terms of MSK scale) of the main shock of the 27 October 1985 earthquake, after Bounif (1990). *Redrawn.*

and careful analysis of the contemporary documents, relative to the 1985 Constantine earthquake, has led to a detailed re-evaluation of how much damage was produced to man-made structures and, to nature and how it was felt by the population. As in past earthquakes in Algeria and elsewhere, adobe, drystone and unreinforced masonry bearing walls constructions experienced serious damage and/or total collapse. Most damage and loss of life were generally observed in regions close to the epicentre. All the sources give evidence on severe damage and destruction of old houses and farms in the zone included between El Khroub, Constantine and Beni Yakoub. The earthquake caused the loss of about 10 lives and injuring 300; it destroyed many adobe and drystone houses, about 25 km southeast of the town of Constantine. This event was associated with important ground surface ruptures which were mapped shortly after the earthquake by Bounif *et al.* (1987). The map of the ground ruptures is shown in fig. 2.

In Constantine itself, the main shock and its early aftershocks caused a general panic. In fact, most of the people had fled their homes to the streets and public gardens, fearing stronger shocks. The modern buildings were slightly damaged while in the old part of the city, in Souika, most of the constructions were seriously cracked. 25 km southeast of Constantine, in the village of El Aria, houses and farms suffered maximum damage. It was reported that five people were killed by the collapse of their

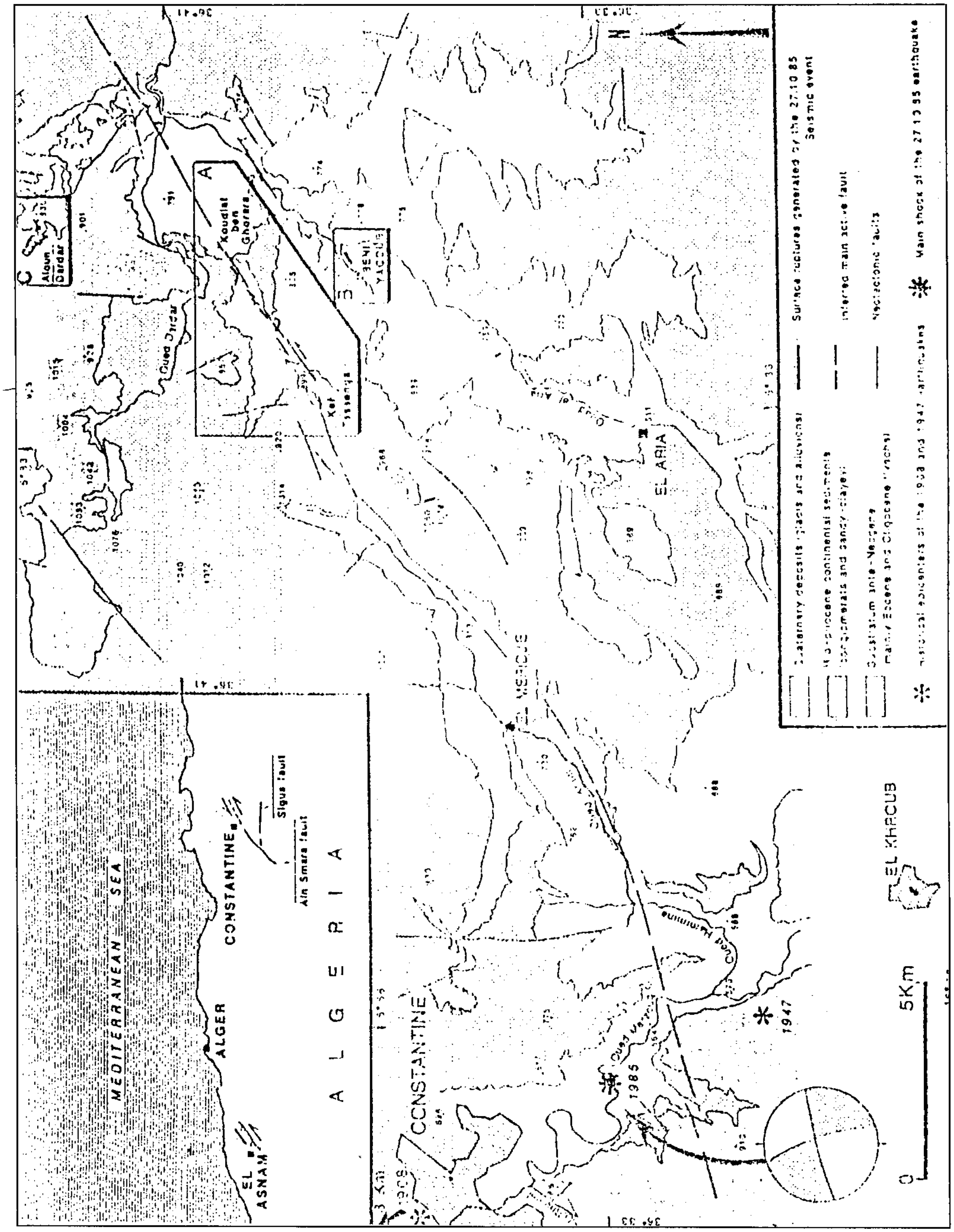


Fig. 2. Map of the affected region showing the ground surface ruptures produced by the 1985 Constantine earthquake, after Bounif *et al.* (1987).

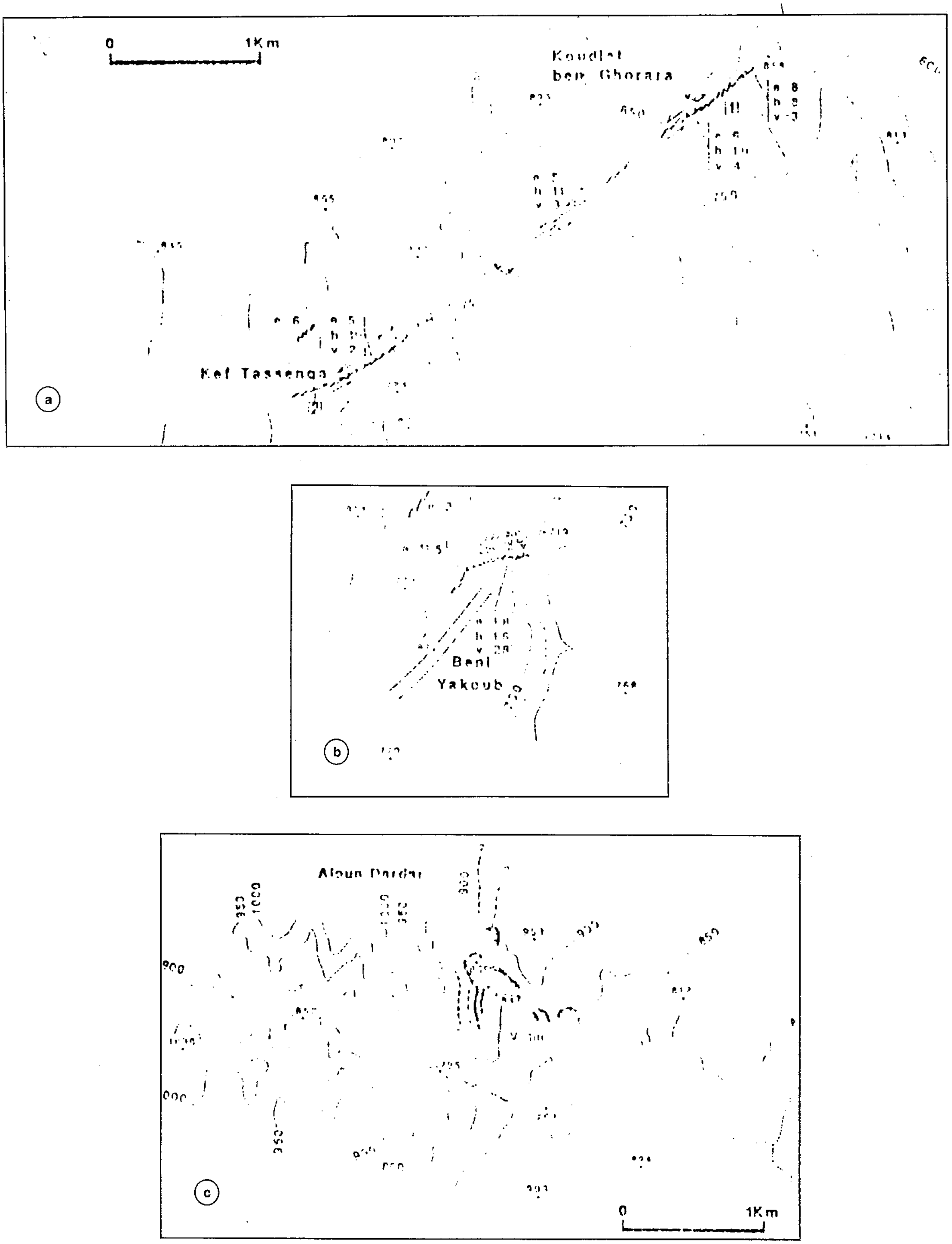
houses and several others were injured when they were fleeing their homes (Press, 1985). Between Kef Tassenga and Koudiat Ben Ghorara, north of Beni Yakoub, the 3.8 km ground surface ruptures appear in small segments showing left-lateral, in echelon pattern, breaks (fig. 3a). The segments of the fissure are approximately 50 metre long while the average left-lateral displacement reached 10 cm. Fissures, in echelon pattern, were observed at Kef Tassenga and Koudiat Ben Ghorara. In Beni Yakoub, 9 km northeast of El Aria, the damage was extensive as many stone houses were completely destroyed. At this site, a 700 metre long ground surface fissure with a west-east trend was produced by the earthquake (fig. 3b). The opening of the fissure varies between 2 and 20 cm, the maximum horizontal displacement is about 18 cm and the depth is between 10 to 50 cm while the vertical displacement reached 28 cm. Aioun Dardar, about 8 km north of Beni Yakoub, is a mountainous zone with deep valleys and steep slopes. The earthquake had produced graben-like subsidence or landslide of different sizes of which the vertical displacement is about one metre (fig. 3c). At El Meridj, at about 9 km east of Constantine, the modern buildings recently built have seen their columns, shear walls and masonry infill walls cracked. Adobe and stone houses were destroyed or seriously damaged. About 13 km southeast of Constantine, in El Khroub, the damage was extensive but slight. According to the detailed CTC mission report about the state of the main buildings (Unite Sonacome, 450 block apartments, Lycée, flour mill Sempac,...), it seems that modern buildings sustained only slight damage as horizontal fissures in staircases, shear wall (reinforced concrete) and masonry infill walls. Several old gourbis and houses were completely destroyed (Press, 1985). In Ain El Abid, 14 km southeast of El Aria, old drystone and adobe houses presented relatively important damage as fall of ceilings and cracks in the walls about one centimetre. In Chelghoum Laid, about 60 km west of El Aria, the shaking, which lasted about 5 s, was so strongly felt that the population panicked. In Annaba, 100 km northeast of El Aria, the shock was widely observed.

It was reported that the region contained between Skikda, Chelghoum Laid, Ain Fakroun and Guelma sustained significant to slight damage. The main shock was reported felt in the region included between Souk Ahras, Batna, Setif and Jijel (Press, 1985; CRAAG and CTC, 1985; Bounif *et al.*, 1987 and 1990).

4. Intensity re-evaluation

Using the macroseismic data collected and standard criteria, intensities were re-assessed with reference to the Medvedev-Sponheuer-Karnik – MSK – 1981 scale. It has been relatively easy to assign intensities to the city of Constantine and its close surroundings for which the different sources (Press, 1985; CTC, 1985; Bounif, 1990) give a good enough descriptive information of the effects of the earthquake on humans, man-made objects and on the ground itself. For a better appreciation of the strength of the shaking, a comprehensive investigation was carried out to reveal the type of constructions that existed and in what state they were, in order to add the macroseismic information already collected and then to re-assess the intensities with a certain degree of reliability. According to the history of the region, the building stock exposed to the shaking consisted of structural types A, B and C as defined by the MSK scale.

Maximum intensity was re-evaluated at VIII (MSK) and was confined to the area contained between El Aria and Ben Yakoub, of about 8 km radius. Intensity VII was attributed to Constantine, El Khroub and El Meridj. Intensity VI was allocated to Ibn Ziad, Hamma Bouziane, Zighout Youcef, Oued Zenati, Ain El Abid, El Harrouch and Azzaba. Intensity V assigned to Skikda, Mila, Chelghoum Laid, Ain


0
1Km
Kef Tassenga
a
Beni
Yakoub
b
c
0
1Km

Fakroun and Guelma. Intensity IV was attributed to Chekfa, Djemila, El Eulma, Ain Yagout, Oum El Bouaghi, Sedrata, Bouchagouf and Ben M'hidi. Intensity III to Souk Ahras, Batna, El Tarf, El Kala, Ain El Hadjar, Setif, Amoucha and Jijel. Intensities VII-VIII were confined to the sites where important damage was produced and, loss of life and injuries were recorded. Intensities V-VI were assigned with a rigid interpretation of the MSK intensity scale (Medvedev *et al.*, 1981). Intensities III-IV were attributed on felt effects and on the evidence of lack of damage to poor-quality constructions; negative reports were also taken into account. Intensity III depicts the boundary of the felt area, assumed, in the absence of very low intensity observations.

As a result of the analysis of the macroseismic data, an isoseismal map of the 27 October 1985 Constantine earthquake has been drawn and is shown in fig. 4.

5. Magnitude determination

Teleseismic amplitude and period readings of the main shock were reported from 18 seismological stations at epicentral distances varying between 12.5° and 95°. Using the standard Prague formula (Vanek *et al.*, 1962) and a preliminary epicentre (Macroseismic) at 36.339°N, 6.924°E, we find that the mean period is 17 s and the derived value of M_S, without station corrections, is 5.70 (± 0.27). The details of the data and the results are given in Benouar (1993).

Fig. 3a-c. a) Main ground surface ruptures in Kef Tassenga and Koudiat Ben Ghorara, after Bounif *et al.* (1987); b) ground surface ruptures observed in Ben Yakoub, after Bounif *et al.* (1987); c) ground deformations (Graben-like subsidence) in Aioun Dardar, after Bounif *et al.* (1987).

6. Foreshocks and aftershocks

The main shock was preceded by at least two foreshocks the same day and followed by a long sequence of aftershocks. Bounif (1990) studied in details the sequence of aftershocks that occurred during the period 2 to 21 November 1985. Witnesses in El Aria region reported that two shocks were felt few hours before the main shock. The first one at 12 h (GMT) and the second at 18 h (GMT) which was accompanied by an explosion. No seismological station reported the first foreshock whereas the second one was reported only by Lodge seismological station (LDG) as:

– date: 1985 10 27; origin time: 17 h 50 min 36 s (GMT); epicentre: 36.300°N, 7.000°E; local magnitude at 3.90.

The main shock was followed by a long sequence of small and moderate aftershocks, continuing until the end of November 1985. The largest ones occurred on 28 October 1985 at 0 h 38 min 57 s (NEIC) with magnitude M_L = 3.90 (LDG), 1 h 54 min 25 s (LDG) with M_L = 3.80, 3 h 39 min 16 s (LDG) with M_L = 3.90 and, on 3 November 1985 at 12 h 32 min 29 s (GMT) with magnitude 4.1 (Bounif) and on 9 November at 11 h 46 min 44 s (GMT) with magnitude 4.0 (Bounif). During the period 2 to 21 November 1985, 622 shocks of magnitude M greater or equal to 1.8 were recorded by the local seismological network, of which 37 of magnitude M greater or equal to 3.0. These aftershocks seriously undermined the spirits of the population of Constantine and its surroundings for many days. It is after an intensive explanation of these aftershocks by Algerian specialists on TV and on the press that people started to join back their homes.

7. Discussion

The 27 October 1985 Constantine earthquake has been the strongest seismic event recorded in the Tell Atlas since the 1980 El-Asnam earthquake and in Constantine

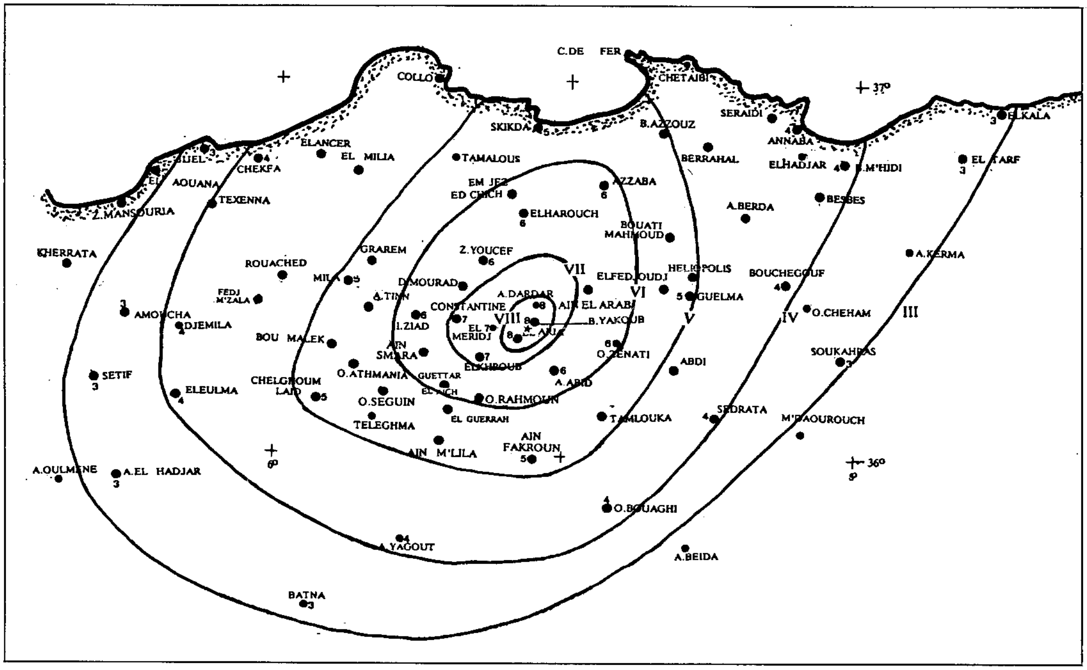


Fig. 4. Isoseismal map (in terms of MSK scale) of the main shock of the 27 October 1985 earthquake. The star shows the macroseismic epicentre.

since the beginning of this century. The most significant seismic events which took place in Constantine region in this century, are manifestly: the 4 August 1908 (M_S = 5.23 (± 0.10), I_0 = VIII) and the 6 August 1947 (M_S = 5.00 (± 0.29), I_0=VIII MSK). It is of interest to know that all damaging earthquakes in Constantine were associated with relatively long sequence of aftershocks and with at least one moderate-magnitude (M $\geqslant$ 4.0) aftershock.

The reconstruction of the macroseismic field of the 27 October 1985 earthquake is of great importance for various reasons. Firstly, it represents the strongest recorded seismic event in Constantine region in this century. Secondly, the same epicentral area, which experienced at least three damaging earthquakes (1908, 1947 and 1985), exhibits many of the humans and geographical characteristics met in other seismic regions of the country. Thirdly, the earthquake affected a relatively densely populated area (third largest in the country). For these reasons, a careful and detailed analysis of the effects of this earthquake on the region is therefore relevant to whole seismic Algeria, in terms of seismic hazard and risk assessment. Detailed study of the 1985 earthquake provides a fundamental basis for mitigating future disasters by recommending ways of strengthening existing buildings, improving local construction techniques, materials and, layout and implantation of new urban and rural sites.

In order to study the earthquakes of the past critically and understand better the information contained in contemporary documents, the historical accounts of each earthquake should be examined in the context of the political, socio-economic and, demographic situations cultural and, religious background and particularly the characteristics of the building stock of the period concerned. In 1985, the political situation in Algeria was seriously disturbed by an armed group who has taken up arms against the government. This fact had monopolized all the Algerian media (all state owned) which made the earthquake fall into a second place. The information contained in the Algerian press is very limited and general. We found strange that no photograph was published nor details of the damage and casualty were communicated. The lack of information was obviously influenced by some kind of censorship which was exercised by the government. At that time, the foreign media was not allowed to report directly from Algeria, unless authorized by the government.

A careful and critical analysis of all the parameters, that may have been involved in the damage as the type of the building stock and its state, were necessary in order to re-evaluate intensities with a certain degree of reliability and avoid overrating. After much consideration of the macroseismic data collected, maximum intensity VIII (MSK) was confined to El Aria and its close surroundings, an area about 8 km radius.

Summarizing the results, we obtain the following final data for the 27 October 1985 earthquake: origin time 19 h 34 min 56 s (GMT); macroseismic epicentre at 36.339°N, 6.924°E; focal depth of about 8-10 km; maximum intensity I_0 = VIII (MSK); magnitude M_S = 5.70 (± 0.27).

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The Chenoua-Tipaza earthquake of 29 October 1989

Abstract
This research appraises one of the largest earthquakes that occurred in the littoral of the capital Alger. The Chenoua-Tipaza earthquake of 29 October 1989 occurred at 19 h 9 min 24 s (GMT); it is the strongest seismic event felt and recorded in the coastal region of Alger. The main shock and its largest aftershock (12 min later) caused the loss of about 35 lives, injuring more than 700 and rendering 50000 homeless; it destroyed and/or seriously damaged around 8000 housing units besides about 500 public buildings. There are no reports about any premonitory signs. The main shock was followed by a long sequence of aftershocks which some of them were strong enough to add casualties among the population and further damage in the affected area. The earthquake was associated with a 4 kilometre long ground surface ruptures observed at Sidi M'hamed, important rockfalls and landslides on the coastal road and on the southern side of Chenoua Mount (904 metres). There are no indications that liquefaction was observed. After critical analysis of the macroseismic data available, maximum intensity is re-estimated at I_0 = VIII (MSK) and allocated to Nador and its close surroundings, an area of about 200 square km. Damage was most significant in Nador, Sidi Moussa, Sidi Amar, Sidi M'hamed, Bakoura, Tipaza and Cherchell. The radius of perceptibility was fairly large, the main shock was felt in Algeria as far as Ain El Hadjar in Wilaya of Saida (285 km away) and in Spain in Balearic Isles (370 km distant), with intensity III (MSK). The main shock triggered strong-motion instruments which indicate a peak horizontal acceleration at 0.28 g with vertical component of 0.14 g at Cherchell about 12 km away. The macroseismic epicentre was located between Nador, Sidi M'hamed and Chenoua Mount, at 36.575°N, 2.401°E. The surface-wave magnitude of the main shock was calculated, without station corrections, at 5.70 (± 0.29). The appraisal of destructive events is of great significance for the assessment of seismic hazard and risk in regions where large earthquakes are not frequent.

1. Introduction

On Sunday 29 October 1989, at 19 h 9 min 24 s (GMT), a destructive earthquake struck the region of Tipaza-Cherchell located on the coast, about 60 km west of the capital Alger. It has reminded once more, only 9 years after the devastating El-Asnam 1980 earthquake, the Algerian authorities about the severity of the social, economic and even political impacts that seismic hazard may cause to the country. The main shock was followed 12 min later by a strong aftershock of equivalent size which, not only, disrupted the relief but increased the casualty toll and damage. The main shock and its strongest aftershock (19 h 21 min 52 s) caused the killing of at least 35 people, injuring about 700 and rendering approximately 50000 homeless; it destroyed and/or seriously damaged about 7500 housing units and 500 other different buildings (official buildings, schools, hospitals, cultural and sport centres, museums, shops, industrial buildings, reservoirs,... etc.) in the area affected. The earthquake was felt in Algeria as far east as Azefoun, south as Ain Oussera and Saida, west as Tiaret and in

Spain as far as Balearic Isles with intensity III (MSK). The main shock and its strongest aftershock were recorded almost by all the stations of the world (517 and 415 stations respectively, NEIC). Their surface-wave magnitude were calculated, without station corrections, at M_S = 5.70 ($\pm$ 0.29) and 5.48 ($\pm$ 0.32) respectively. It apparently seems that the main shock was not preceded by any kind of premonitory observation.

The whole of the Wilaya of Tipaza suffered major damage where more than 25 percent of its building stock were destroyed or damaged beyond repair, 58 percent sustained moderate to heavy damage and can be repaired at considerable cost and 17 percent experienced slight damage (CGS-CTC, 1989). The earthquake affected structures within an area of 22000 square km, with intensity V^+ (MSK). Most damage was most concentrated in the sites of Nador, Sidi Moussa, Sidi M'hamed, Menaceur, Bakoura, Sidi Amar, Tipaza, Cherchell and their surroundings. As an example of damage, in the village of Nador itself, with a population of 6500 inhabitants, it was reported that at least 13 people were killed, 150 injured and, all the old colonial constructions and local traditional houses (adobe and masonry) were destructed (Press, 1989). After much consideration of the macroseismic data collected from field visits and the documentation available, maximum intensity has been re-evaluated at I_0 = VIII (MSK). The zone of maximum intensity is relatively well documented and covers an area of approximately 8 km radius, centred in southwest of Tipaza.

The 1989 Chenoua earthquake was associated with ground surface ruptures of about 4 km fault length, 7 cm vertical displacement observed in the southern side of Mount Chenoua and numerous rockfalls which demolished houses, parapets and obstructed the coastal road between Cherchell and Tipaza. Landslides were also observed on the coastal road and on the southern side of Mount Chenoua. Details of the observed ground features were mapped shortly after the earthquake by Meghraoui (1991). There are no reports of ground liquefaction.

The most reliable information on ground motion during an earthquake is obtained from recordings of strong-motion accelerographs. The main shock of the 1989 Chenoua earthquake triggered seven strong-motion instruments at the sites of Alger, Cherchell, Tenes, Miliana, Khemis Miliana, Medea and Arbaa (CGS, 1989). The closest instruments where those of Cherchell, Alger and Medea. The analysis of these records give a peak ground horizontal acceleration at 0.28 g at Cherchell, 0.044 g at Medea and 0.036 g at Bouzareah (CGS, 1989 and Ambraseys *et al.*, 1990).

2. Sources of information

The 1989 Chenoua-Tipaza earthquake is well documented with a variety of source materials. This earthquake was largely commented in the Algerian press, not only because of the casualties and major damage it caused, but also because of the disturbances it caused for at least two weeks in the affected region. The most extensive account is given in «El-Moudjahid» (1989), a state owned daily newspaper.

Since 30 October 1989, the CGS and CTC (two governmental bodies) teams started their survey work to directly and officially report the extent of the damage to the Algerian authorities. They published an internal mission report and drawn an isoseismal map (fig. 1). The CRAAG team was also dispatched in the affected zone since the 30 October 1989; they published an internal mission report and drawn an isoseismal map (fig. 2). The Civil Engineering Institute (University of Bab Ezzouar) team, of which I was a member, have visited the affected zone on 1, 5 and 8 November 1989 and summarized the effects of the earthquake in a mission report. Ambraseys *et al.* (1990), Imperial College team, have also visited the affected area and published

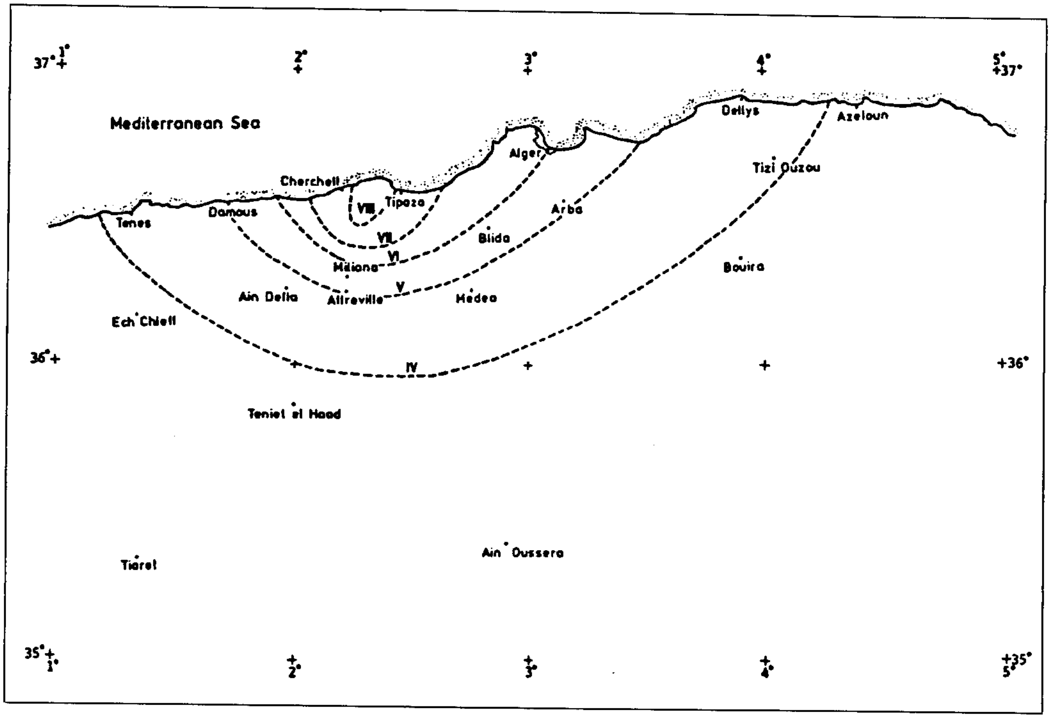

Fig. 1. Isoseismal map (in terms of MSK scale) of the main shock of the 29 October 1989 earthquake, after Boudiaf, CGS (1988).

an internal research report. Boudiaf (1990) has visited the damaged region (CGS team) and, published a preliminary internal report on the Chenoua earthquake and its consequences. Meghraoui (1991) who has also visited the zone concerned (CRAAG team) has published a detailed study of ground deformations with an isoseismal map (fig. 3).

The 1989 Chenoua-Tipaza earthquake and it strongest aftershock (19 h 21 min 52 s) were recorded by most of the seismological stations in the world (respectively 517 and 415, NEIC). Instrumental epicentre locations of the main shock were calculated at 36.773°N, 2.447°E (NEIC), 36.615°N, 2.326°E (CRAAG) and 36.50°N, 2.40°E (CSEM). The magnitudes were also determined at $M_S = 6.00$, $m_b = 5.7$ and $M_{SZ} = 5.7$ (NEIC) and $M_L = 6.1$ (0.2) (CRAAG). Maximum intensity VIII (MSK) was assigned by CRAAG, CGS-CTC and Meghraoui (1991) to the area containing Nador, Cherchell, Sidi Moussa, Tipaza and surroundings.

3. Geographical aspects of the epicentral region

The sahel (Littoral) of Alger is the narrow band which extends from Alger to Cherchell, about 100 km long; it is contained between the Mediterranean sea and the Mitidja plain. Wide about 20 km in the east and only few in the west, the sahel presents a smoothly broken relief. Its altitude varies from 407 m in Bouzareah (Alger) to

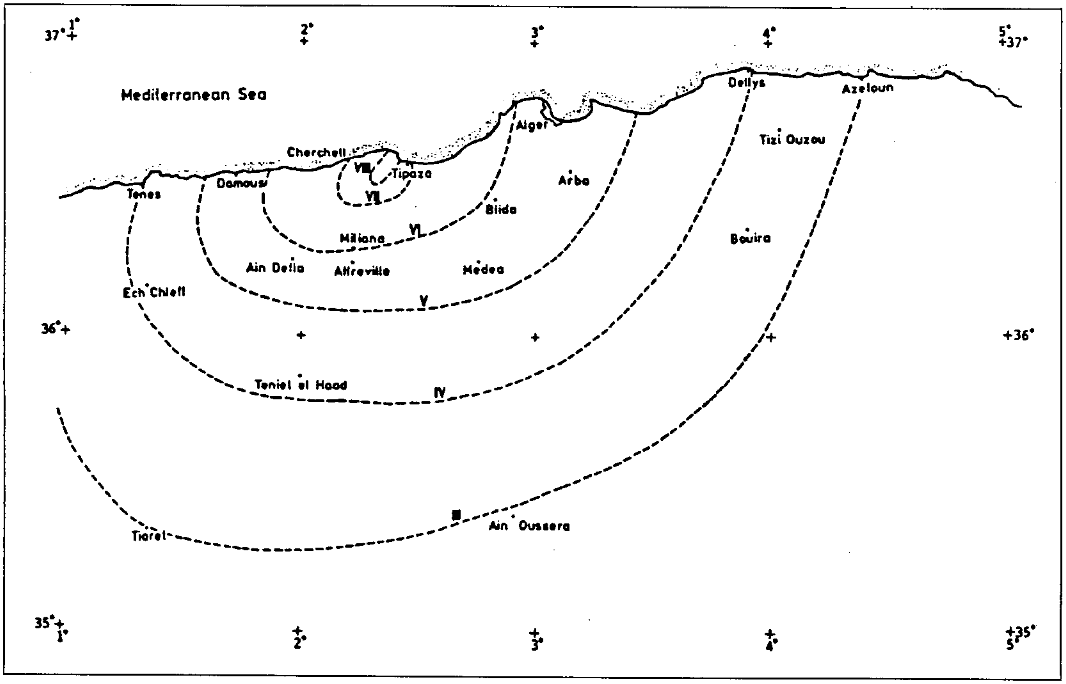

Fig. 2. Isoseismal map (in terms of MSK scale) of the main shock of the 29 October 1989 earthquake, after CRAAG (1988).

88 m in Tipaza and then abruptly raises to 907 m in Chenoua Mount. Besides the charm of the landscape, the sahel of Alger, due to its long history, is a real open museum full of history and art vestiges. The main cities which constitutes the sahel of Alger are Tipaza, Cherchell and Alger which have a long and well-recorded history. Tipaza, an old phoenician trade counter, became a latin colony in the 1 st century AD and a roman colony in the 2nd. In 371 AD, the Berber chief Firmus tried to take it but in vain. In 484, the Vandal king Huneric, willing to force the catholics of Tipaza to embrace the arian heresy, made many of the inhabitants leave Tipaza looking for asylum in Spain. Then, the Byzantines took over the town in 534 and later the Arabs who gave it the name of Tefassed (damaged). Cherchell is also an old town; it was a phoenician colony, founded in the 4th century AD. Later, Juba II expanded the city and changed its name to Caesarea which became the capital of the Roman Algeria.

4. Historical seismicity of the affected area

In terms of the seismic history of the affected region reported by Rothé (1950) and, Ambraseys and Vogt (1988), it appears that the coastline between Alger and Cherchell has experienced moderate to large earthquake in the past. We notice that four seismic events equivalent to that of 29 October 1989 earthquake occurred in the close surroundings of Tipaza-Cherchell area, that is at Cherchell (1735), Hadjout (1756), Kolea (1802) and Cherchell (1847)

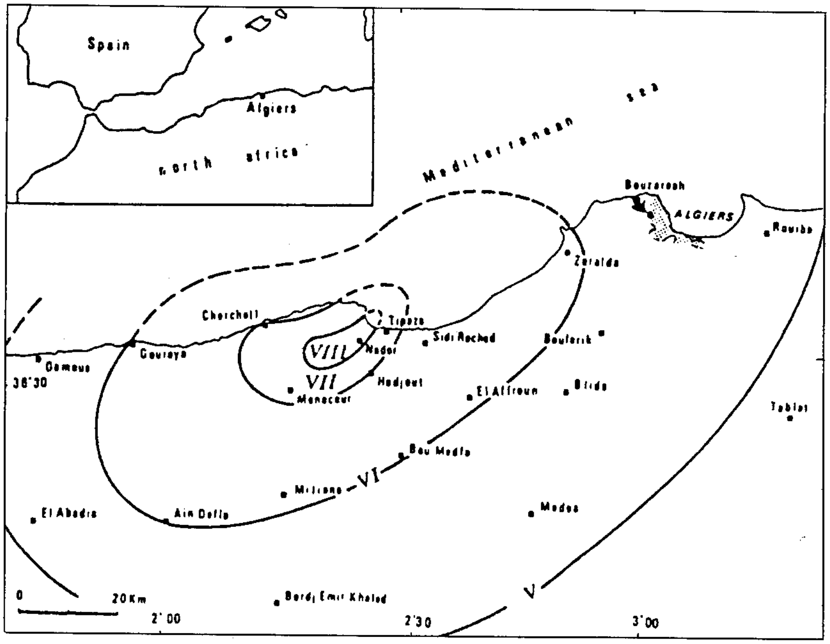

Fig. 3. Isoseismal map (in terms of MSK scale) of the main shock of the 29 October 1989 earthquake, after Meghraoui (1991).

(fig. 4). It is of intertest to mention that historical and recent earthquakes along the coast between Alger and Cherchell often pointed out vertical ground motion. Since 1847, the seismic activity of this coastal region has decreased notably. There have been since then and up to 1988, 4 moderate events at Douera on 5 November 1924 (VIII MSK, 4.9), Cherchell on 7 November 1934 (4.6), Bou Medfaa on 7 November 1959 (VIII MSK, 4.9) and Oued Djer on 31 October 1988 (VIII MSK, 5.6).

Since small to moderate size earthquakes are likely to occur in the same area affected, which is now densely populated (about 160 inhabitants per square km), during the 1989 Chenoua-Tipaza earthquake, it is imperative that, in order to mitigate future seismic disasters, seismic hazard and risk be evaluated. According to the history of Algeria, the Cherchell-Tipaza region should have a long recorded history. Certainly, several previous earthquakes, equivalent to the 1989 Chenoua earthquake, should have occurred in the area but, unfortunately, some of them are still unknown. Numerous vestiges of the past are still visible in the region and should be studied in detail, in order the reconstruct the historical towns and villages in the region. Today, archaeoseismology and palaeoseismology techniques may be applied in Tipaza-Cherchell region to eventually reveal historical destructive earthquakes and thus, to extend the time range of seismic history.

5. Building stock characteristics

Due to its agricultural vocation, the whole wilaya of Tipaza is mostly a rural residential area, more than 50 percent of the population live in small colonial villages

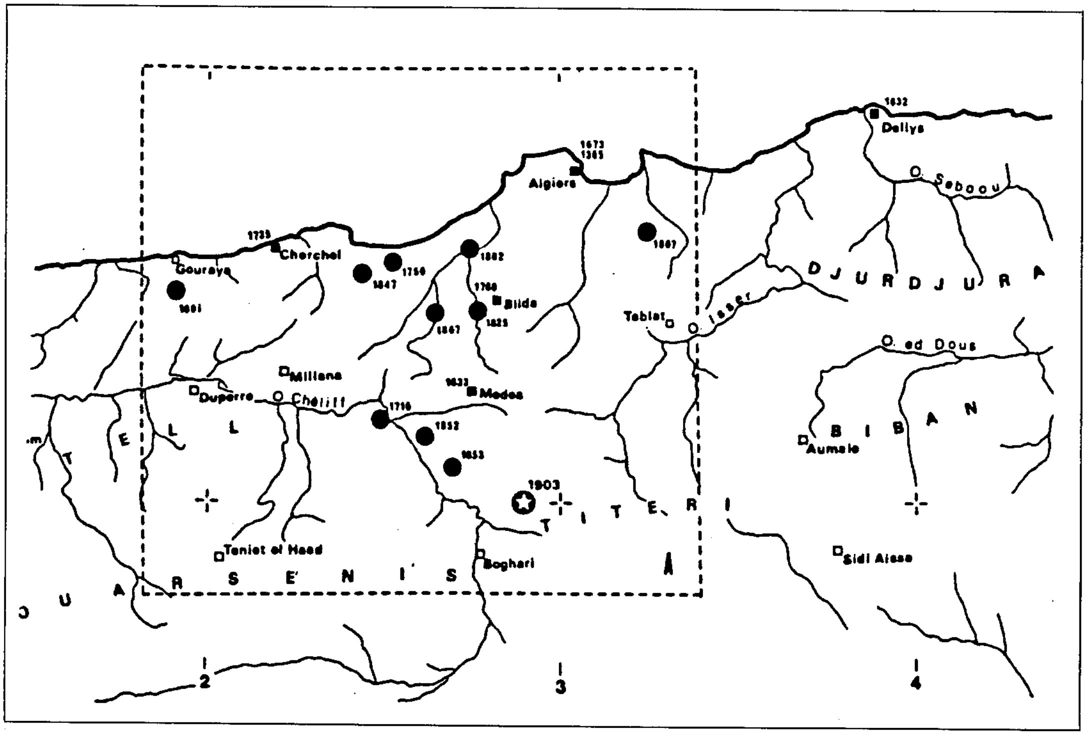

Fig. 4. Map of the historical seismicity of the province of Alger (inset), showing the historical destructive earthquakes in the sahel of Alger, after Ambraseys and Vogt (1988).

and scattered douars in the valleys and mountains (Armature Urbaine 1987, 1988). Apart from the few small industrial plants, official buildings, hospitals, schools, cultural and sport centres, markets, newly built villas and public work constructions, most of the old housing are adobe, drystone and unreinforced masonry (burned bricks or concrete blocks). Nevertheless, such constructions are still existing in more urbanized areas as Cherchell and Tipaza. Some old constructions date from the XVIIth century such as the Casbah at Cherchell. The characteristics of the building stock, as in other northern parts of Algeria, are mainly associated with the regional history of development. In the affected zone, the building stock, prior to the 1989 earthquake, varies between four storey high modern buildings to single storey adobe house (gourbis). It could be divided with respect to its type of structures into the three following categories:

1) traditional native housing (gourbis) which is predominant in rural zones (douars). Most of them have survived previous earthquakes and were repaired more than once;

2) non-engineered ordinary masonry buildings and reinforced concrete structures which constitute about 60 percent of the housing building stock in the area;

3) engineered modern structures which are generally built since 1970.

The constructions of the first category are mainly the traditional local stone-mud or mud-straw houses (gourbis) with heavy roofs (described previously in detail). The second category consists of constructions built during the colonial period and up to 1970. This type of building which is non-engineered masonry is predominant in villages. The masonry constructions (burned bricks or concrete blocks) are characterized by thick walls, heavy floors and tile roofs. Floors and roofs are resting on joist of timber which are simply embedded a few centimetres into the wall masonry, but, unfortunately, opposite walls were not tied to each other which facilitated the destruction. The non-engineered reinforced concrete constructions are generally two way structures. The floors are constituted with hollow precast elements with a 4 to 5 cm thick overtopping reinforced concrete slab cast in-situ. The resulting slab of the floor is about 20 cm thick. Interior and exterior walls are generally built of hollow precast concrete blocks or burned bricks infill. Generally, the apartment buildings are commonly built on a short crawl space (vide sanitaire), which is used for water, gas, sewage pipes and vertical ventilation shafts, supported by short columns. Constructions of the third category which are engineered structures built with aseismic design and construction regulations PS 69 (French) and RPA 81 (Algerian). The majority of these structures are up to five storey high; they are reinforced concrete frames with hollow bricks, concrete blocks or reinforced concrete panels infill. Most constructions built after 1980 were built with reinforced concrete shear walls. The floors are either built with precast reinforced concrete shallow beams supporting hollow precast elements or with a reinforced concrete slab cast in-situ. The foundations consists of footings tied with beams of 45 to 65 cm deep or general raft. Unfortunately, constructions with soft story and «vide sanitaire» which were widely used in the past are still being built. The typical building is two bay wide (7 to 8 m including the corridor) by 10 bay long (about 30 m). This type of construction consists of concrete columns and beams, concrete or composite slabs and, masonry interior partitions and exterior infill. Typically, the building stock in Algeria presents a high vulnerability to large earthquakes. But what makes these structures, old and new, so weak before the earthquakes is the lack of maintenance and neglect. Rehabilitation and repair are hardly ever carried out with the intention of strengthening of the structure. As of a matter of fact, the introduction of new materials such as reinforced concrete in the absence of proper aseismic design and building codes and enforceable regulations has developed a new type of vulnerable structures.

6. Damage and casualty distributions

Compilation and careful analysis of the contemporary documents relative to the 1989 Chenoua-Tipaza earthquake has led to a detailed re-evaluation of how much damage was produced to man-made structures, and to nature and how it was felt by the population. As in past earthquakes in Algeria and elsewhere, adobe, drystone and unreinforced masonry bearing walls constructions experienced total collapse or serious damage. The epicentral area within which the shock caused heavy damage and casualties accommodated about 620000 people living in about 85000 houses. The main shock, which lasted about 20 s, and its largest aftershock (19 h 21 min 52 s) caused the loss of about 35 lives, injuring approximately 700 and rendering around 50000 homeless; it destroyed about 7500 housing units and 500 public edifices. Most damage and casualty were observed in the epicentral zone around the Chenoua Mount and to the south at Nador, Sidi Moussa, Sidi Rached, Sidi Amar, Menaceur, Tipaza and Cherchell. Nador (Daira of Hadjout), located at about 6 km southwest of Tipaza and accommodating 6500 inhabitants, is a very poor Baladia (City) without any resources. The majority of its population live from the agriculture which, unfortunately, was seriously affected by the six year drought. Here, the shock was so violent to cause people flee from their homes to the streets and free fields in a total panic. The screaming of the women and the children, the crash of the falling masonry, the total darkness and the dust turned the night into a veritable inferno. All the population had spent the night in the surrounding fields waiting for the morning so they can have food and shelter. The main shock and its largest aftershock caused the destruction of about 600 housing units and damaged around 1000, mainly in the dependent douars of Nador where three-quarters of the constructions collapsed. It was reported by the press (1989) that about 22 people were killed and 300 injured in the whole of the Baladia (City). As to damage to structures, all the old houses built in the colonial period were destroyed as well as the adobe houses. The same words were repeated by the witnesses: «... it is a miracle that we are still alive, thanks to God. Our houses are very old and in an advanced state of deterioration; many of them were converted from colonial cellars...». Even new built houses suffered significant damage, as an example, a new villa just completed had seen its ground floor seriously damaged (soft story). The earthquake caused serious damage to the masonry abutments of the bridge, at Oued Hachem, leading to Nador where cracks and settlement were observed. The deck of this bridge was displaced in the north-south direction. The other bridge, at Sidi Ben Youcef, was seriously cracked and had to be strengthened by steel supports. In Sidi Moussa (Baladia of Nador), about 4.5 km southwest of Nador, the same scene prevailed; all the houses are destroyed or heavily damaged. North of this small locality, at Irane Tizi, segments of 100 metre long cracks were observed. Sidi Moussa is the douar who suffered most damage and casualty. Up in the surrounding hills of Nador about 3 km northwest away, a hamlet called douar Nora Lamouren which was described and suggested as the macroseismic epicentre (Press, 1989). Accounts of newsmen reported that: «... we followed for more than 2 km through valleys and hills, a long ground surface fissure. Here, the damage of the houses (gourbis) was 100 percent and five children were trapped and killed under the debris of their stone houses...». Also, about 1 km northeast of Sidi Moussa, the Marabout Sidi Oussrour was totally destroyed. The longest and most remarkable ground ruptures are at Sidi M'hamed, 6 km northwest of Nador, where two segments, each of about 150 m long linear unbroken cracks cross-cut a hillside. The details of the ground ruptures were mapped shortly after the earthquake by Meghraoui (1991) and are in fig. 5.

In Tipaza, the capital of the wilaya, 3 km east of the Chenoua Mount, the main shock was so strong to make all the inhabitants flee from their homes. The population was, all in a flutter, camping in the streets and the public gardens. It was reported that an old lady died of an heart attack after the main shock. The earthquake destroyed or seriously damaged about 700 housing units and public buildings, rendering around 5000 homeless. Homeless people camped for several months under the tents in the roman ruin site in Tipaza. Five km east of Tipaza, numerous douars, which are perched and sparsely distributed on the impressive Mount Chenoua (904 m), although not mentioned by the press, sustained important casualty and damage. As in other mountainous douars, most of the constructions were in adobe, stones or non-engineered masonry and thus could not resist the shakings. The Chenoua Mount itself was seriously shaken by the earthquake. Rockfalls which in some cases demolished houses, walls and parapets, ground ruptures and landslides were observed in many places. In Beldj, on the eastern foot of the Mount, most of the houses were destroyed or heavily damaged and the majority of the population were camping under the tents. Significant damage was caused to the

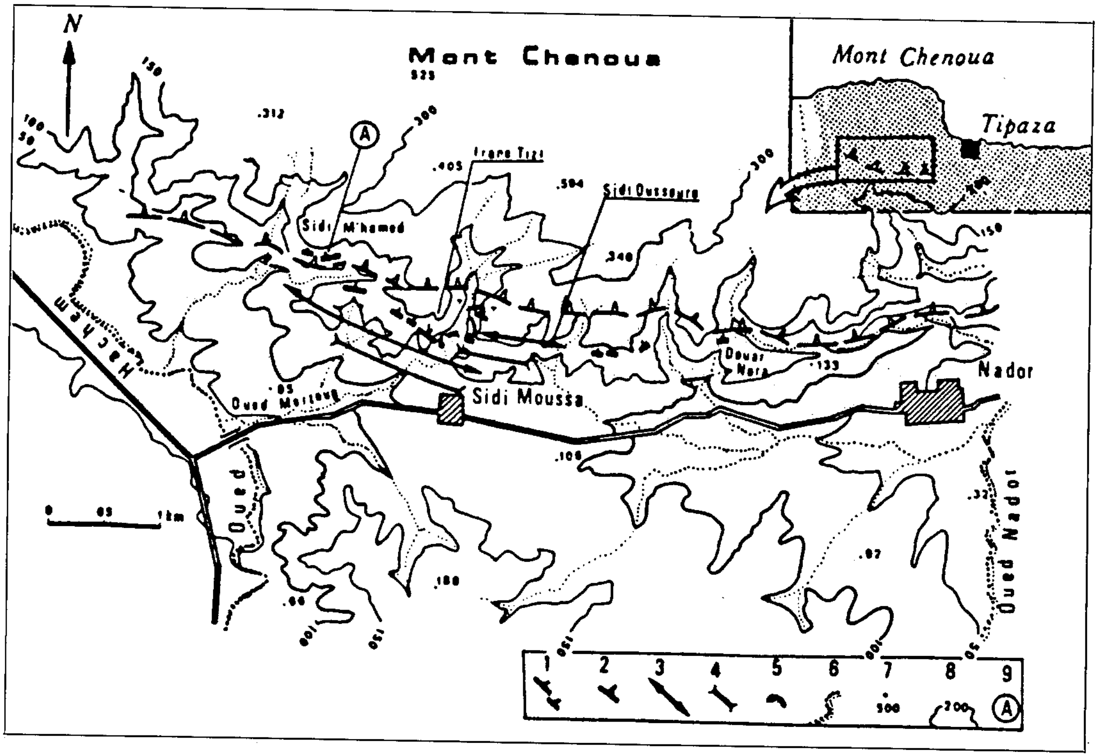

Fig. 5. Map showing the surface ground ruptures of about 4.0 km of interrupted cracks south of Chenoua Mount. 1) Surface ruptures; 2) neotectonic fault; 3) anticline; 4) syncline; 5) landslides; 6) river; 7) topographic elevation; 8) topographic contour; 9) location of fissures, after Meghraoui (1991).

Mosque of the locality; the minaret seriously cracked at its base, lost its dome.

In Cherchell, the second largest city in the wilaya, 23 km west of Tipaza, accommodating about 18000 people that time, the main shock was strongly felt. The population panicked and left their homes to the streets, fearing other strong shocks. All the constructions of the Daira (County or Borough) of Cherchell were badly shaken and many collapsed completely. It was reported that, in the whole daira, about 3000 (40%) housing units were destroyed or badly damaged making approximately 21000 homeless. The city lived a whole night in the darkness without electricity which made the relief difficult and accentuated the disaster. The head of the Daira reported that 4 people were killed and 25 injured in the city of Cherchell. But, in the surrounding douars sparsely distributed in the mountains, the sorrow was installed in many families. The majority of the population had spent the night in the open; they refused to join back their homes as a witness reported that the population was repeating: «... we prefer spending the night here in the open fields better than caught asleep in our beds...». In the city itself, besides the housing units destroyed (900), several public edifices were seriously damaged or heavily fissured. It was reported that 7 secondary schools (CEM), the tax office building, 2 primary schools, the central pharmacy buildings and the CTC (Controle Technique de Constructions) building were destroyed. Both museums of the city were seriously shaken (cracks and crush down of statues). The new one suffered mainly non-structural damage, particularly to the brittle brick coating of the reinforced concrete columns and beams. The old museum, built in 1908, suffered slight damage. The old parts of Cherchell, particularly Ain Casibah (Casbah) and Cite Thiziri were heavily damaged. The buildings at Ain Casibah, built between 1600 and the beginning of this century, were hard hit. The bearing walls were built of rubble and stone masonry with lime mortar or traditionally burned bricks with a mud mortar. The roofs consisted of wooden joists which were resting on the walls without any tie. Deep diagonal cracks, corner ruptures and, walls separating from floors and ceilings were reported in most old houses. Several old houses in this site were threatening of collapse or were damaged beyond repair. It was reported without any details that the most damaged surrounding douars were the «farms» Morsli, Sidi Mesbah and Sidi Boulazzouz. In the 1980 El Asnam earthquake, 80 houses were completely destroyed and many more seriously damaged in the Daira of Cherchell. In Bakoura (city of Cherchell), one of the few cases of significant damage caused to modern reinforced concrete structures was the school, built in 1982. The school suffered damage beyond repair and was demolished after the earthquake. Furthermore, one of the most predominant causes of failure were the short columns. The police club, a two-storey brick masonry building, sustained heavy damage. The timber roof of the building collapsed and cantilever slabs considerably damaged, corner failures and walls fissured. It is important to mention that the population of Cherchell and its surroundings have protested on Tuesday 31 October 1989, in obstructing the national road from 8 h in the morning to 16 h because of the lack of relief (no shelters, no food,... etc.). They complained also about the government attention which was directed only toward Nador while Cherchell and many other sites in the mountains were badly affected. The administrative authorities called the gendarmerie, which used tear gas bombs, to break up the crowd (victims of the earthquake). This fact shows that there were no emergency management programme for the region.

In Sidi Amar (Daira of Hadjout), 14 km southwest of Tipaza, the main shock was strongly felt which made the whole population flee from their houses to the free fields. It was reported (Press, 1989) that the earthquake caused the loss of at least two lives, injuring 5 and rendering about 6500 homeless; it completely destroyed or heavily damaged 911 housing units (645 rural and 266 urban). The rate of destruction was more important in the rural mountainous zones where sometimes damage reached 100 percent. The sole secondary school (CEM) of the village sustained major damage and so was closed. The school teachers' residence was destroyed by the failure of short columns of the «vide sanitaire». Four km southeast of Tipaza, the small village of Sidi Rached was strongly shaken by the earthquake. The population fled from their homes to the open in a total panic. It was reported that 260 houses were completely destroyed, 60 badly damaged and about 200 slightly cracked, making about 2000 homeless. The numerous destroyed or badly damaged houses and the establishment of tents almost everywhere in the city were offering to the passengers a scene of great desolation. No details about the casualty were communicated. In Hadjout (Daira), 10 km south of Tipaza, has lived a «white night» as reported by its inhabitants. The earthquake was strongly felt to make the population flee in panic from their houses to camp in the open for the whole night, fearing other strong shocks. An account reported that the earthquake was preceded by an explosion and followed by a deafening rumbling. A witness reported that: «... for me, Hadjout was going to be razed from the earth surface. We were brutally ejected to the ground; the roofs crushing down over our heads, the buildings were swaying before our eyes. We were waiting for the worst...». The main shock and its strongest aftershock caused at least the loss of 12 lives, injuring more than 100 (Press, 1989) and rendering approximately 9000 homeless; it destroyed and/or seriously damaged about 1300 housing units in the whole Daira. The secondary school (CEM) Mouloud Feraoun, the Lycee, the maternity hospital, the pharmacy of the hospital, the Bank (BADR) buildings, the Daira (Bourough offices) buildings and the gendarmerie buildings were heavily damaged. Meurad (Daira of Hadjout), 13 km south of Tipaza, accommodating 4500 people living in about 700 houses. The earthquake destroyed about 50 housing units and seriously damaged some 400 and making about 2000 homeless. In the rural zones, 30 houses were completely destroyed and many more damaged in the douars of Ferdjana, Boudjerroune, Belhadj and Doumia and, 15 in Meurad itself. The deaf mute school as well as the Baladia building (city hall) sustained significant damage. Bourkika, 11 km southeast of Tipaza, experienced the same fate as Sidi Rached about 2 km away. It was reported that about 200 houses were completely destroyed and/or heavily damaged making about 1200 homeless. At about 20 km southwest of Tipaza, the small village of Menacer sustained serious damage. As other villages in the region, the whole population was all in panic and fled from their houses to the open. It was reported that the main shock and its largest aftershock destroyed 940 houses and seriously affected about 300, making approximately 7000 homeless.

The Daira of Kolea (Wilaya of Tipaza), 30 km east of Tipaza, sustained significant damage. It was reported that about 75 houses totally collapsed and a hundred damaged. In Bou Ismail, a colonial village, 22 km east of Tipaza, damage was observed in many masonry buildings.

The Daira of Zeralda (Wilaya of Tipaza), 40 km east of Tipaza, was also significantly affected. The earthquake destroyed about 60 houses and badly damaged 150. In the Daira of Cheraga (Wilaya of Tipaza), which is at 50 km east of Tipaza, the earthquake was so strong to make people flee from their homes. It caused the destruction of about 60 houses and the damage of 95 others.

In Blida (Wilaya of Blida), 40 km southeast of Tipaza, the population panicked and rushed outdoors. It was reported that 4 buildings of the locality called «Douerates» were slightly damaged whereas an old construction at Sidi El Kebir was heavily damaged.

The earthquake was strongly felt in Tissemsilt (Wilaya of Tissemsilt), about 125 km southwest of Tipaza, where the population had fled from their homes.

In the capital Alger, 60 km east of Tipaza, the earthquake was strongly felt; the population panic-stricken had left their homes to the streets and public gardens. The main shock occurred at 20 h 09 min (Local Time) when the majority of the people were watching the 8 o'clock news. The newsreader, instead of giving advice to the population, panicked and left his seat rushing outdoors as the whole population. The electricity was interrupted for few minutes. Few seconds after the main shock, the streets of the capital were full of distressed people. Numerous cars were seen, full of people, leaving the city looking for safe shelters in the suburbs. The earthquake caused significant damage to the oldest parts of the city as Casbah, Bab El Oued, Belcourt, Kouba, Badjarah, El Hamma and El Harrach. Witnesses reported that people were repeating: «... We thought that the old houses of the Casbah (oldest part of the city) were going to collapse according to their decayed state. We were asking ourselves how a so strong shaking did not cause the tragedy we are waiting for many years...». The houses of the Casbah, built during the Ottoman period, are stone and mud constructions which make them vulnerable even to heavy rain. As it was reported, each winter, new cracks were observed in the buildings; the earthquake had only accentuated the already weakened and damaged houses (age, rain, wars, earthquakes, neglect and improper repair). The main shock and its strongest aftershock destroyed 6 houses in the Casbah and Bab El Oued and caused significant fissures in the «Haute» and «Basse» Casbah in the Mira (ex. Malakoff) and N'fissa streets. About 40 families, from the Casbah and Bab El Oued, had left their homes and gathered with their furniture and goods in the Place of Martyrs (Centre of Alger), fearing the collapse of their buildings. Six days after the earthquake, a building accommodating 6 families collapsed killing one person and injuring 5. Around the Casbah, the population squattered at least 9 schools and were gathered in groups of six to seven families per classroom. The historical site of Djennane Beit El Mal (a vestige of the Ottoman period) which displays an advanced state of deterioration is now accommodating more than 20000 people in very old houses waiting for the next disaster. The largest hospital of the capital, Hospital Mustapha, lived a general panic from 20 h 30 min (local time) until the next morning. Few minutes after the earthquake, the emergency pavilion was «assaulted» by the victims particularly young men (under 35 years of age). A 40 year old man died by a heart attack while an other died from fear. The earthquake had severe psychological effects on the population; for several weeks, people were talking and arguing about magnitude, intensity and earthquake prediction. To add to their confusion and anxious state, Haroun Tazief (French volcanologist) declared from France that the city of Alger will be destroyed by a stronger earthquake in the near future which created a terrible polemic in the country.

In Bordj El Bahri (Wilaya of Boumerdes), across the Alger bay at about 75 km east of Tipaza, where I was during the earthquake and lived few minutes of fear and panic. All the family was watching the 8 o'clock news when suddenly we heard an increasing underground rumbling which was followed first by vertical and then horizontal oscillations. The masonry house was all shaking. We all left the house and rushed outdoors to the garden. The electricity was interrupted for few minutes. No damage was reported in the village and its surroundings. In Boumerdes itself, the shaking was strong enough to make people flee from their houses. Two people were reported to have been injured when they thrown themselves from their apartment windows.

In Ain Defla (Wilaya of Ain Defla), 60 km southeast of Tipaza, the earthquake was so strong that people fled from their homes. Damage was reported to be slight as cracks in walls and plaster.

In Medea (Wilaya of Medea), 45 km southeast of Tipaza, it was reported that people had fled from their houses to the streets and gardens. Old houses sustained slight damage as small cracks in the walls.

One hundred and fourtyfive kilometres east of Tipaza, in Tizi Ouzou (Wilaya of Tizi Ouzou), the earthquake was strongly felt but no damage was reported. The shaking was slightly felt up to Azefoun, west of the Wilaya.

In Saida (Wilaya of Saida), 285 km southwest of Tipaza, the earthquake was strongly felt particularly by the population of Ain El Hadjar (south of Saida) where some people had left their homes (Press, 1989).

In the Balearic Isles (Spain), 370 km north of Tipaza, it was reported that the earthquake was felt indoors by many people and outdoors by few people. The vibration was like that due to a passing train. It was reported that the earthquake was slightly felt at Tenes, Echeliff, Theniet El Had, Ksar El Boukhari, Dellys and Bouira in Algeria and in Spain as far as Balearic Isles.

7. Intensity re-evaluation

Using all the macroseismic data available to us, intensities were re-assessed anew with reference to the Medvedev-Sponheuer-Karnik - MSK - (1981) intensity scale. For a better estimation of the strength of the ground shaking, an extensive search was carried out to reveal the various types of constructions that existed at that time and in what state they were, in order to add the macroseismic data available and thus to re-evaluate the intensities with a satisfied degree of reliability. Compilation and critical analysis of the data collected has led to a detailed re-assessment of the amount of damage inflicted to humans, man-made structures and to the ground itself. The old constructions in adobe, stones and non-engineered masonry have sustained most damage. It is true that, particularly, the adobe and stone houses (gourbis) have suffered decay through ageing, negligence, rain, improper repair and earthquakes. Many houses were already seriously affected during the 1980 El-Asnam earthquake. In contrast with the non-engineered constructions, the most recent buildings which were conceived and built according to the aseismic design and construction regulations (RPA 81) did not suffer, in general, any structural damage except in few cases. One of these exceptions is the 12 apartment block building at Cherchell which had shown important structural damage in the ground floor because its initial destination was changed to commercial space and thus created a «soft story». This type of conversion produced other constructive dispositions as openings in fanlight which form short columns.

As a consequence of the defectiveness of the non-engineered (adobe, stones and ordinary masonry) structures, the maximum intensity in any destructive earthquake in the colonial villages and the douars appears to be the same. That is, at intensity IX-X on the MSK scale, most of the houses are totally destroyed and any douar or old village would thus look equally, but no more, devastated at higher intensities of the scale. Therefore, high intensities (IX-XII), in many parts of Algeria, can only be evaluated from the behaviour of engineered structures.

After a careful analysis of the macroseismic data collected, maximum intensity was re-evaluated at I_0 = VIII (MSK) and allocated to Nador, Sidi Moussa, Sidi M'hamed and Mount Chenoua, an area of about 8 km radius. This intensity was assigned to the zone associated with maximum damaged structures, significant ground deformations and loss of life. Intensity VII was confined to Tipaza, Cherchell, Hadjout, Menacer, Meurad, Sidi Rached and Bourkika. Intensity VI was attributed to Zeralda, Kolea and Cheraga. Intensity V was assigned to Alger, Blida, Bordj El Bahri, Ain Taya, Rouiba, Boumerdes, Medea and Damous. Intensity IV was allocated to Tizi Ouzou, Dellys, Bouira, Ksar El Boukhari, Theniet El Had, Echeliff, Tenes and Balearic islands (Spain). Intensity III was assigned to Azefoun, Ain Oussera, Tiaret, Ammi Moussa, Ain El Hadjar (Saida). Lower intensities V to VII are consistent with a rigid interpretation of the intensity MSK scale (Medvedev *et al.*, 1981). Most the low intensities III to IV were allocated merely on the felt effect and on the evidence of lack of damage to low-quality types of constructions.

As a result of the analysis of the macroseismic data available, an isoseismal map of the 29 October 1989 Chenoua-Tipaza earthquake has been drawn and is shown in fig. 6.

8. Magnitude determination

The surface-wave magnitude of the main shock of the 1989 Chenoua-Tipaza earthquake is computed by using teleseismic amplitude and period readings from 34 seismological stations located at distances between 14° and 92°, a preliminary epicentre (macroseismic) at 36.57°N, 2.40°E and the standard Prague formula (Vanek *et al.*, 1962). The data and the results are presented in Benouar (1993). The mean period is 16.5 s and the derived value of M_S, without station corrections, is 5.70 ($\pm$ 0.29).

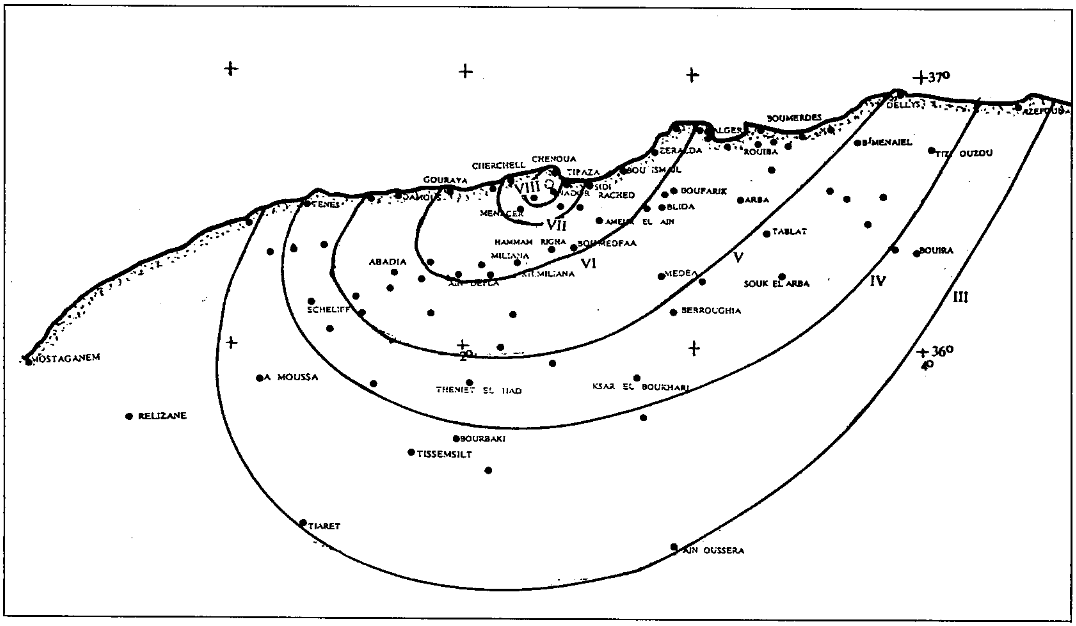

Fig. 6. Isoseismal map (in terms of MSK scale) of the main shock of the 29 October 1989 earthquake. The star shows the macroseismic epicentre of the main shock (GMT).

9. Foreshocks and aftershocks

We have found no evidence that the main shock was preceded by any kind of premonitory observations. The main shock was followed by a long series of aftershocks. During the period 31 October 1989 to 20 December 1989, more than 1300 aftershocks of magnitude $1.0 < M < 5.0$ were recorded in the epicentral region (Meghraoui, 1991). The largest aftershocks were observed mainly during the first week following the main shock.

The strongest aftershock occurred, 12 min after the main shock, at 19 h 21 min 52 s (GMT). It was strongly felt in the same area as of the main shock (Press, 1989). This aftershock, not only, disrupted the tiny relief but added significant casualty and damage in the Cherchell-Tipaza area. It was widely recorded by 415 the seismological stations in the world (NEIC, 1989). The teleseismic data from 8 stations were used with the standard Prague formula to calculate the surface-wave magnitude of this aftershock. The details of the data and the results are given in Benouar (1993). The mean period and the derived M_S value, without station corrections, is 5.50 (0.32).

Among the largest aftershocks, that of Saturday 4 November 1989 at 19 h 20 min (GMT) which was felt in Tipaza region and as far as Alger. It was reported (Press, 1989) that it caused major damage in Cherchell area. The shaking was so strong to make people flee from their homes and camp again in the streets and surrounding free fields. Its magnitude was calculated at $M = 4.3$ (CRAAG). The continuity of the aftershocks had raised, to the paroxysm, the nervous tension of the whole population of the area affected. It was reported that the region lived for two weeks a state of siege because the population in the whole of the Tipaza-Cherchell region was, all in a flutter, asking for considerable relief.

10. Discussion

By its size, the Chenoua-Tipaza earthquake is the largest seismic event felt and recorded in the coastal region of Alger. It occurred very close to the epicentres of the early destructive earthquakes which are reported in the Tipaza region in 1735, 1756, 1802 and 1847 (Ambraseys and Vogt, 1988), therefore, the 1989 earthquake is by no means an exceptional one. These four historical events may be related to a coastal source of seismic activity between Tipaza and Alger (Meghraoui, 1991). In contrast with the size of shocks normally used as the basis for aseismic design and building regulations (French Recommendations AS 55 and, PS 69 and Algerian RPA 81) and the theoretical estimates of the seismic hazard obtained from incomplete and inhomogeneous data sets which did not predict a peak ground acceleration exceeding 0.15 of g (Mortgat and Shah, 1978a,b), (fig. 7) and 0.03 of g (Hattori, 1988), (fig. 8) in the Chenoua region. Thus, it should be noted that the seismic hazard in Algeria must be re-evaluated in the framework of the historical and instrumental seismicity of the country.

This earthquake shows the potential for a higher degree of time and space inhomogeneity of seismicity in the coastal Tipaza-Cherchell region and the consequences of this in the assessment of seismic hazard in Algeria.

The reconstruction of the macroseismic field of the 29 October 1989 earthquake is of great interest for various reasons. Firstly, it represents the strongest felt and recorded seismic event in the littoral of Al-

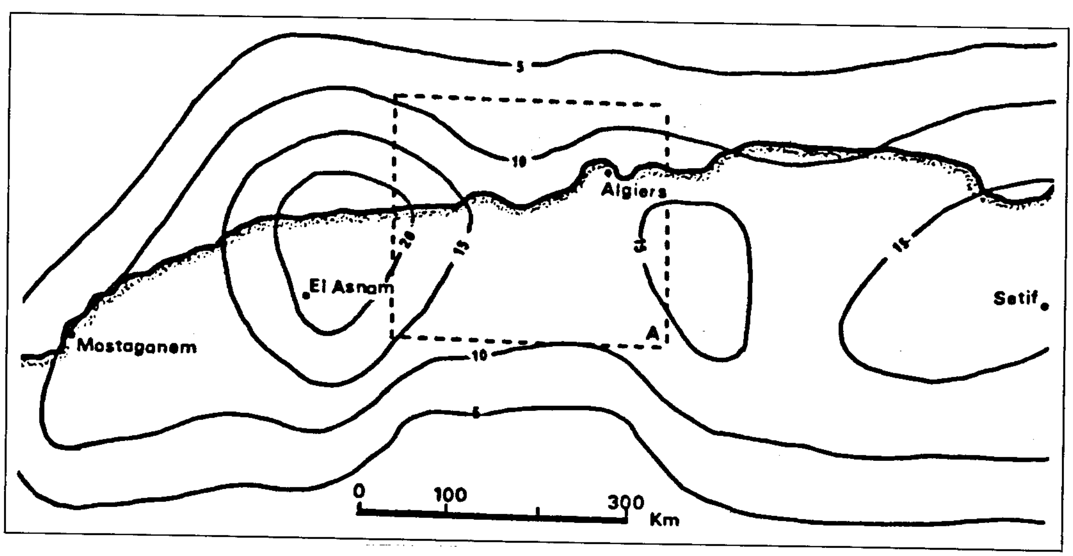

Fig. 7. Map of the seismic risk in North Algeria after Mortgat and Shah (1978a,b). Contours show the maximum horizontal ground acceleration (% g) calculated for an annual probability of exceedance of 1%. Inset shows the extend of the sahel of Alger.

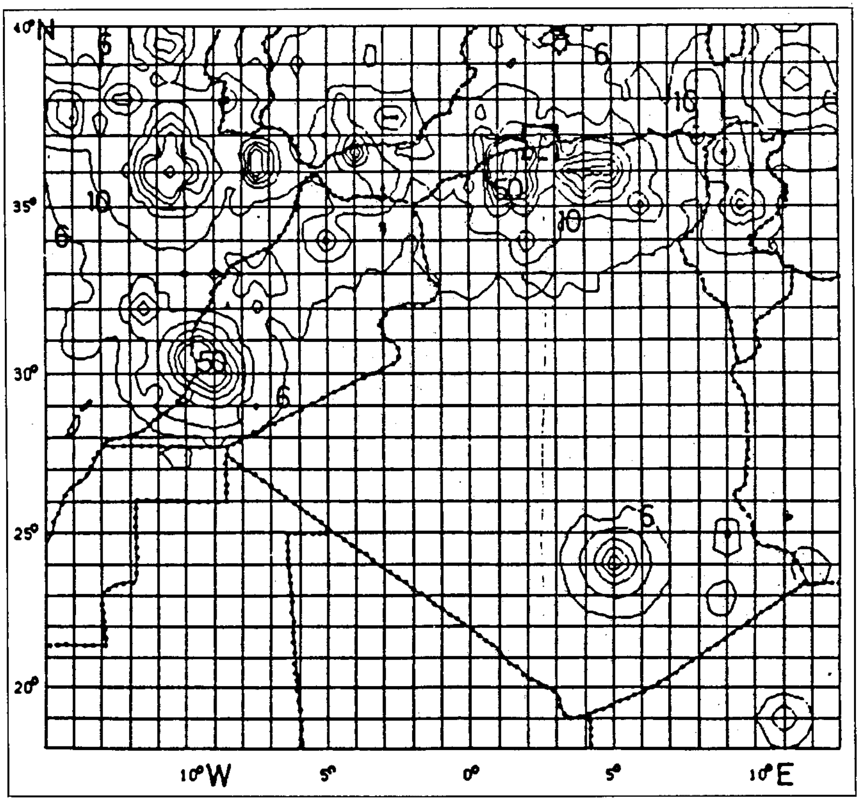

Fig. 8. Map of the seismic risk in the Maghreb region after Hattori (1988). Contours show the regional distribution of maximum acceleration (gal) for a return period of 100 years. Inset shows the sahel of Alger.

ger-Cherchell region. Secondly, the same epicentral area, which experienced destructive earthquakes in the past (1735, 1756, 1802 and 1847) displays today many of the humans and geographical characteristics met in many other regions of Algeria. Thirdly, it affected a relatively densely populated area, more than 150 inhabitants per square km (Armature Urbaine 1987, 1988). For these main reasons, a detailed study of the effects of this earthquake on the region is therefore pertinent to the whole of the seismic Algeria, in terms of seismic hazard and risk evaluations. It provides a fundamental means for the mitigation of future seismic catastrophes by proposing new ways of improving local construction procedures, building materials, strengthening and properly repairing existing buildings, layout and implantation of new urban and rural sites.

Compilation and critical analysis of the contemporary documents relative to this earthquake has led to a detailed evaluation of how much damage was produced and how the population behaved. However, we should keep in mind that most damage (65%) was sustained by adobe, stone and non-engineered masonry constructions whereas recent modern engineered building did not suffer any structural damage, except in few cases where it was mainly due to short columns (CGS-CTC, 1989). After much analysis of the macroseismic data collected, maximum intensity was re-evaluated at I_0 = VIII in the MSK scale and allocated to Nador, Sidi Moussa, Sidi Amar and Chenoua Mount, an area of about 8 km radius.

However, to study critically the earthquakes of the past and for a better understanding of the information contained in contemporary documents, one should examine the historical accounts with in mind the political, socio-economic and, demographic conditions, cultural and, religious background and the characteristics of the building stock of the period concerned (Ambraseys and Melville, 1936b). One year before the earthquake, on Wednesday 5 October 1988, most of the Algerian people, unhappy about the whole situation of the country, has taken to the streets in every town and broken down and burned every state institution (Wilaya, Daira, Baladia, commercial centres, industrial plants, buses,... etc.), asking for better living conditions. To stop the uprising, the President called out the army which killed hundreds of people and injured many more; the details were not communicated. This killing event seriously complicated the situation which pushed the president to promise democracy to the people. Since then, besides the precarious socio-economic conditions which were worsening every day and which the Algerians lived for the last 6 years, Algeria entered an unstable political and socio-economic period. The period of the earthquake was characterized for the Algerians by total deception, unemployment, lack of adequate medicine and particularly housing (national occupancy rate about 7.5 by housing unit) (Armature Urbaine 1987, 1988). Due to its agricultural vocation and the 5 year drought that preceded the earthquake, the 29 October 1989 earthquake seriously affected the standard of living of most of the inhabitants of the Wilaya of Tipaza. Because of the overall instability and despite the visit of the Prime Minister in the same day in the affected region, the administrative authorities were not prepared to respond adequately to this type of disaster. They launched the plan ORSEC (Organisation de Secours) or the emergency management programme three days after the earthquake (Press, 1989). Even when the programme was implemented, the authorities showed a lack of experience, coordination and emergency means. Many victims of Nador and Cherchell, which were not reached by the authorities or the relief teams, obstructed the national roads which complicated the situation and disrupted the tiny ongoing relief. The gendarmerie had to intervene, using tear gas bombs, to break up the crowd. Besides the earthquake disaster, the political and mainly the daily socio-economic conditions complicated the situation. The people of the affected area, taking the opportunity of the disaster, were trying to solve their everyday life problems. In fact, everybody who was unhappy with his home (old, isolated, damaged, crowded,... etc.) was asking for a tent, because as reported by the press: «... having a tent during that period means that you are homeless and will be accommodated in a new state apartment...». This overall situation, which reigned during two weeks, may explain why the details of casualty and damage were not communicated by the mass media (all state owned). The press (1989) gave a casualty toll as 23 killed and 196 injured which we believe was much higher since many sparsely distributed hamlets and douars in the mountains, which could have enriched the data, were not mentioned in any report. According to the macroseismic data collected, we believe that the affected zone was not declared disaster area only because of the financial capabilities of the government.

One of the conclusions that may be drawn from this seismic event is the ease with which the Algerian housing and other constructions were damaged. Wether it is old traditional houses or modern constructions, the buildings had shown a low strength and a very high vulnerability to the recurrence of destructive earthquakes, particularly in rural zones.

Summarizing the results, we obtain the following final data for the 29 October 1989 earthquake: origin time 19 h 9 min 24 s (GMT); macroseismic epicentre at 36.575°N, 2.401°E; focal depth about 6 to 8 km; maximum intensity I_0 = VIII (MSK); magnitude M_S = 5.70 (± 0.29).