Appendix B

Case studies of major earthquakes

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The Boghari earthquake of 23 September 1903

Abstract
This research examines the largest destructive earthquake accurred in this century in the Boghari region, which is on the southern flank of the Ouarsenis massif. On the 23rd of September 1903, at 1 h 55 min (GMT), the region of Boghar was struck by a destructive earthquake. According to the seismic history of the region, the same epicentral zone has been the site of several damaging seismic events in the last two centuries. The main shock, which lasted 5 s, was strong enough to cause the collapse of many local traditional dwellings (gourbis) in Moudjebeur and its immediate vicinity. The shaking was strongly felt in the whole area encompassing Alger, Miliana, Arba, Blida and Medea, where it awoke people and caused panic among the population. The earthquake was preceded by two foreshocks, but details concerning aftershocks are missing. We found no report of ground deformation or signs of liquefaction. The main shock was recorded mainly by Milne seismographs. The surface-wave magnitude was computed, without station corrections, at 5.50 (± 0.15). Compilation and detailed analysis of the macroseismic information inferred from contemporary accounts have led to a re-estimation of intensities in several sites. Maximum intensity has been re-evaluated at I_0 = VII (MSK) and allocated to Moudjebeur. From the intensity data, an isoseismal map has been drawn and a macroseismic epicentre located, northeast of Moudjebeur, at 36.00°N, 2.83°E.

1. Introduction

On the 23rd of September 1903, at 1 h 55 min (GMT), the region of Boghari was struck by a destructive earthquake. The epicentral area, which centred in Moudjebeur, is located at 95 km south of the capital Alger. The main shock, which lasted 5 s, destroyed many local traditional houses (gourbis) in Moudjebeur (10 km northeast of Boghari). Details of casualties and homeless among the population, and cost of damage were not communicated. The earthquake was strong enough to awake people and cause panic in the zone containing Alger, Medea, Miliana, Lodi, Arba, Boghar and Boghari. It was partially perceived in Theniet El Had and Aumale. We could find no reports further away in the east part of Algeria, or the south or west. The main shock was preceded by two foreshocks, but we found no evidence of any aftershock except the slight quake noticed in Blida on 26th, at 12 h 25 min, which could possibly be one. No reports of ground deformation or sign of liquefaction were found in contemporary accounts. It is reported in the press (Le Tell, 30/9/1903) that in Moudjebeur the flow of the spring had increased four times while in the hot springs of Hammam Righa the temperature had risen by 2°C. The earthquake was recorded by 14 seismological stations through Europe and Asia. The surface-wave magnitude of this event has been computed, without station corrections, at 5.50 (± 0.15).

In order to reconstruct the macroseismic field of this earthquake, a broad investigation of contemporary documentary materials relative to this event was carried out. The results of this search have led to a re-evaluation of the extent of damage to both man-made structures and nature, and to an appreciation of the behaviour of the population. From the analysis of the macroseismic information retrieved, intensities have been re-estimated in several sites. Maximum intensity has been re-evaluated at I_0 = VII (MSK) and allocated to Moudjebeur. From the intensity data, an isoseismal map of the earthquake has been drawn and a macroseismic epicentre located, in Moudjebeur, at 36.00°N, 2.83°E.

2. Sources of information

It was thought that information about this earthquake would be abundant, particularly in the Algerian and French press. Unfortunately, this was not so; the information was rather scarce and confined to colonial villages. The most extensive accounts are given in «La Dépêche Algérienne» (1903). Compilation of data from the press and other contemporary documents has been accomplished by Ambraseys and Vogt (1988) who published a resume of the earthquake and assigned a maximum intensity of I_0 = VII (MSK) to Moudjebeur. Sieberg (1932), without quoting his sources, published an isoseismal map (fig. 1) of the main shock of this event and attributed an intensity of VII (MS) to the region of Blida.

In the recent catalogues, the instrumental epicentre was calculated at: 36.46°N, 2.83°E (Mezcua and Martinez, 1983). The macroseismic epicentre was reported at 36.0°N, 2.5°E (Karnik, 1969); 36.2°N, 2.7°E (Munuera, 1963); 36.33°N, 2.60°E (Ambraseys and Vogt, 1988). Maximum intensity was attributed at I_0 = VIII (MS), (Karnik, 1969); VII (MSK), (Mezcua and Martinez, 1983; Ambraseys and Vogt, 1988) and m_b = 6.0 (Munuera, 1963).

3. Geographical aspects of the region

The epicentral area lies on the southern flank of the Ouarsenis massif. This part of the massif contains a mountainous zone at which the height is around 1000 m, Kef Sidi Amar culminating at 1993 m. The affected zone was remote and sparsely inhabited. It contained several small villages and douars from which, even in recent times, it would not have been easy to infer damage data that would help to locate a macroseismic epicentre. According to contemporary written accounts available to us, the building stock, exposed to the shaking, consisted mainly of poorly built local traditional dwellings (gourbis) made of mud-reed, mud-straw or drystones with thick lime or clay mortar joints and covered with heavy roofs. This type of structure is classified as type A on the MSK intensity scale. A general observation about this prevailing construction is that its inherent strength is very low and extremely variable and its vulnerability to earthquakes, or even to heavy rain, is extremely high.

4. Damage and casualty distributions

Detailed study of the macroseismic information retrieved has considerably contributed in the re-evaluation of the amount of damage experienced by man-made structures and by the ground itself, and how the population behaved. The building stock prevailing during the earthquake was mainly constituted of adobe and drystone bearing wall structures with heavy roofs. It is also true that most of the houses were in an advanced state of decay through ageing, heavy rain, earthquakes, neglect and especially lack of proper repairs. For these reasons, it is unlikely that intensity VIII (MSK) was clearly reached, and thus it became very important to attempt a re-assessment of the macroseismic data augmented with the new information that we retrieved (this study) from the local and national Algerian press.

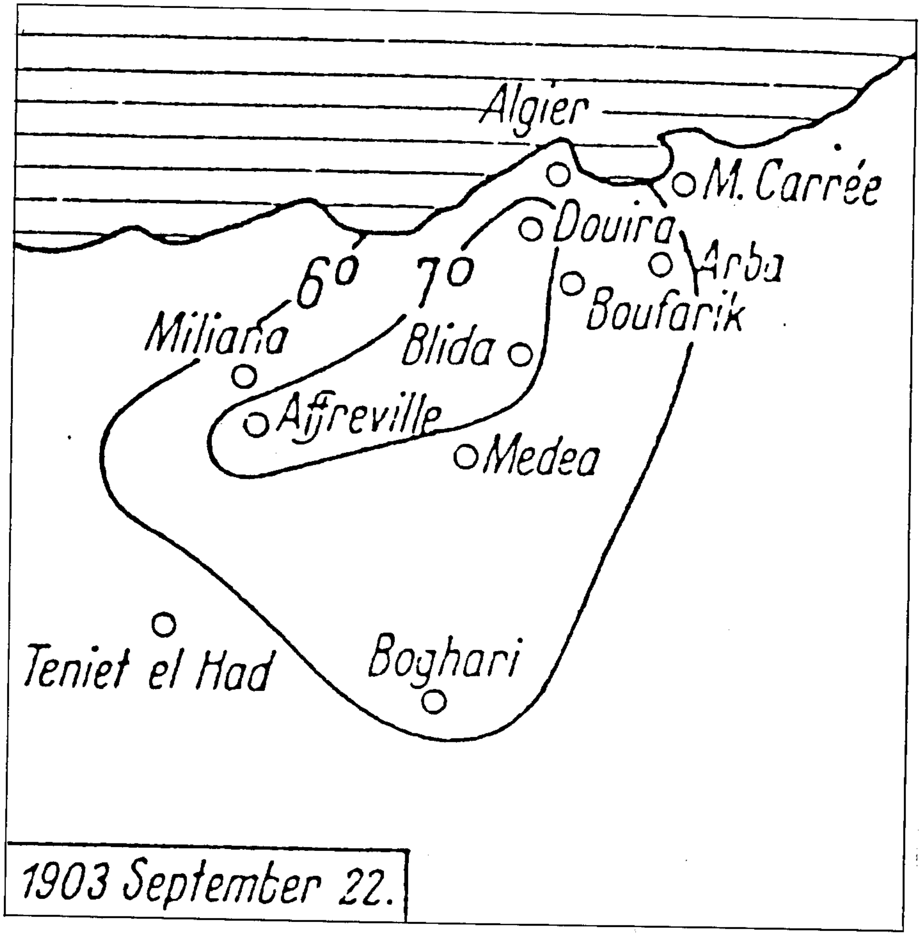

Fig. 1. Isoseismal map (MS scale) of the main shock of the Boghari earthquake of 23 September 1903, after Sieberg (1932).

In Moudjebeur, a small douar located at about 10 km northeast of Boghari, the main shock was strong enough to cause the collapse of several local traditional housing units and the fall of gables in the army (Zouaves) barracks. No details about casualties and homeless among the population were communicated. In Boghar the main shock, which lasted 5 s, caused a great panic among the inhabitants. Damage was slight and consisted mainly of broken glass and cracks in the ceilings of many houses. In Boghari, some walls of the army hospital were fissured and damaged and cortnices destroyed. In a bad state, the walls of the army engineers pavillon collapsed, (Vogt, 1993). Further to the northwest, in Affreville, a small colonial village located 60 km of Boghar, the earthquake caused slight cracks in some houses. The oscillations were in the E-W direction. About 60 km to the north, in Blida, two strong shocks, separated by a relative calm of three seconds, were so seriously felt that most of the inhabitants fled their homes. The total duration of the two shakings was evaluated at 15 s; they were accompanied by an underground rumbling which awoke the population. The bells and the clock in the church steeple rang for 8 s. Most damage consisted of cracks, observed in numerous buildings. In Douera, a village located at about 80 km north of Boghar, the shock was strong enough to cause some inhabitants to flee from their houses to the open. Most observed damage consisted of significant fissures in the walls of the old buildings of the hospital. The duration of the shaking was 10 s. In the capital, Alger, about 100 km north of Moudjebeur, the earthquake was violently felt and lasted about 6 s. The main shock caused a considerable panic among the population in certain quarters of the city. Women and children were gathered in public places. No damage or casualties among the population were reported. In Hussein Dey, 5 km east of Alger, the earthquake, which lasted between 6 and 8 s, was as strongly felt as in the capital. Further east, in Maison Carrée, the shock was strong enough to awake some inhabitants. The earthquake was also felt strongly in Arba and Rovigo, about 80 km distant from Boghar, where it woke a few people of whom some ran outdoors. The oscillations were in the NE-SE direction. In Lodi, a small village located at 40 km north of Boghar, the shaking was so strong that most of the inhabitants fled their homes. The earthquake was preceded by an underground rumbling which awoke the population; it caused several large fissures in all the walls of the buildings and fear about the wine vats (concrete) was seriously mentioned (Vogt, 1993). In Boufarik the main shock, which lasted 7 s, caused great concern among the population, of whom several fled their homes. In Cheraga the population was abruptly awaken; it was also reported that many clocks stopped, many objects overturned and most of the people stayed in the open (Vogt, 1993). In Rivet the inhabitants were also abruptly awaken, bottles shaken and fear of animals were observed (Vogt, 1993). In Mouzaia-Mines fear of livestock was reported. In Attatba and Kherba, the shaking was reported as violent, but no details are given (Vogt, 1993). In Miliana the shock was so strong that many people ran outdoors. In Medea, 40 km north of Boghar, two shocks were felt in the time span of 30 s and were strong enough to make some inhabitants flee their homes. In Bou Medfaa great panic was caused among the population. In Chebli the main shock produced slight damage to the old buildings and caused considerable concern to the inhabitants as well as to the animals and particularly to dogs which barking was also reported (Vogt, 1993). In Theniet El Had the shock, which lasted 10 s, was slightly felt. The oscillations were in the W-E direction. In Aumale, 90 km east of Boghar, the earthquake was also slightly felt. We found no reports on ground deformations or signs of liquefaction, but two hydrological information were given. In Moudjebeur, the flow of a spring increased fourfold and in the hot springs of Hammam Righa the temperature rose by 2°C (Le Tell, 30/09/1903). The search for additional details of the extent of the damage continues.

5. Intensity re-evaluation

All the macroseismic data collected from the sources available to us were used, with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale, to re-estimate the intensities.

After a detailed and careful analysis of the macroseismic information available, a maximum intensity of I_0 = VII (MSK) has been allocated to Moudjebeur and its immediate vicinity. This intensity has been allocated to the site associated with collapse of structures. Intensity VI has been assigned to Boghar, Boghari, Miliana, Affreville, Medea, Lodi, Blida and Douera. This intensity has been allocated to sites which experienced slight damage and to locations where people were alarmed and ran outdoors. Intensity V has been assigned to

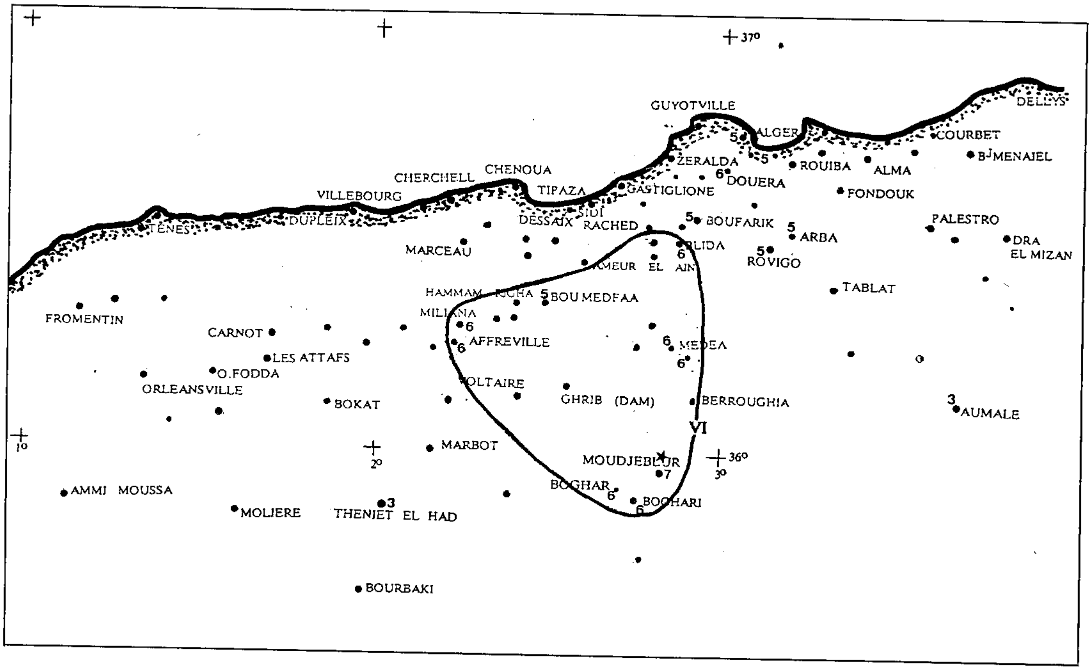

Fig. 2. Isoseismal map (MSK scale) of the main shock of the Boghari earthquake of 23 September 1903. The star shows the macroseismic epicentre of the main shock.

Bou Medfaa, Boufarik, Chebli, Rovigo, Arba, Maison Carrée, Hussein Dey and Alger. Intensity III has been confined to Theniet El Had and Aumale.

From the intensity data, an isoseismal map of Boghar 23 September 1903 earthquake has been constructed and shown in fig. 2.

6. 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 one station (GTT) located at a distance of 16°, and a preliminary epicentre (macroseismic) at 36.00°N, 2.83°E. The data and results are given in Benouar (1993). The mean period is 16 s and the derived value of M_S, without station corrections, is 5.46 (± 0.005). The magnitude has also been determined using amplitude readings from undamped Milne penduli at 5 stations. Employing the calibration formula derived by Ambraseys and Melville (1982) for this type of instrument:

$$M_S = \log (2At) + 1.25 \log (d) + 4.06 \quad (6.1)$$

where 2At is the double amplitude in mm and d the distance in degrees; we found that the equivalent M_S, without station corrections, is 5.50 (± 0.15). The data and results are also presented in Benouar (1993).

7. Foreshocks and aftershocks

The main shock was preceded by two foreshocks, which occurred on the 22nd of September at 23 h at Theniet El Had and at

Affreville on 23rd at 1 h 44 min (main shock at 1 h 55 min), and which were relatively far away from the epicentral area (La Dépêche Algérienne, 23/09/1903). A slight shock was noticed at Blida on the 26th of September at 12 h 25 min which may be taken as an aftershock (Le Tell, 30/09/1903). For both foreshocks and aftershocks the search for additional details continues.

8. Discussion

In terms of the seismic history of the region reported by Hée (1950), Rothé (1950, 1969), Benhallou and Roussel (1971), Mezcua and Martinez (1983), Benhallou (1985) and Ambraseys and Vogt (1988), the same epicentral area has experienced several destructive earthquakes in the last two centuries. The 23 September 1903 earthquake constitutes the first and largest seismic event that occurred in the Boghar region this century.

The study of this earthquake is of great importance for the region for a number of reasons. First, it represents the largest earthquake in this particular region. Second, the same epicentral zone, which experienced destructive earthquakes in the past, exhibits today many of the human and geographical characteristics found in other parts of the country. For these reasons, a detailed appraisal of the effects of this event in the region is thus pertinent to all of seismic Algeria, in terms of seismic hazard and risk evaluation. This earthquake, being the largest in the area, contributes considerably to the reduction of seismic risk by the recommendation of new ways of improving local construction procedures, building material characteristics, strengthening and repairing existing structures, layout and implantation of new urban and rural settlements. To re-evaluate the impact of the earthquake in the region with a certain degree of reliability, an extensive search for source documentary materials relative to this event has been carried out. The result of this investigation shows that most damage was observed in Moudjebeur (10 km northeast of Boghar) and consisted of the collapse of numerous local traditional houses (gourbis). However, for a better understanding of the information contained in the contemporary accounts, we have carefully studied the effects of the earthquake 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 French colonization period, in which many colonial settlements were founded, at the end of the last century. The area was relatively sparsely inhabited, with no large towns or villages and a few scattered douars. The douars or native Algerian settlements could have substantially enriched the data, but they are not mentioned. It was thought that information would be readily available, especially in the Algerian and French press. Unfortunately, it was found to be rather scarce and limited to colonial villages. We also find it surprising that the shock did not cause any casualties among the population, which was caught asleep in houses of very low resistance. Furthermore, no statistics on damage, homelessness or cost of damage were communicated. During that period, reports rarely gave loss statistics for non-European settlements. This subject has been discussed in details in section 1. Chapter I. The search for additional details of the impact of this earthquake in the region continues.

During colonization periods in Algeria and elsewhere, it is of great importance that macroseismic data be extrapolated from contemporary military sources which, because of their official character, contain ample and reliable information.

Summarizing the results, we obtain the following final data for the Boghar earthquake of 23 September 1903: origin time: 1 h 55 min (GMT); instrumental epicentre: 36.46°N, 2.83°E (SSIS); macroseismic epicentre: 36.00°N, 2.83°E; maximum intensity I_0 = VII (MSK); magnitude $M_S = 5.50$ ($\pm$ 0.15).

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The Constantine earthquake of 4 August 1908

Abstract
This research appraises one of the most destructive earthquakes that occurred in Constantine since the beginning of this century. The Constantine earthquake of 4 August 1908 occurred at 2 h 11 min (GMT); it is the first felt and recorded earthquake in this region. The main shock, which lasted about 10 s, and its aftershocks, had a devastating effect on the whole community. The earthquake caused the loss of about 12 lives, injured several and destroyed numerous houses, farms and important public buildings. The radius of perceptibility was fairly small, the shock was felt in La Calle with intensity V^+ (MSK) about 175 km away. The main shock was followed by a series of aftershocks and the earthquake was associated with significant ground surface rupture. After considerable analysis of the macroseismic information retrieved from the sources available, maximum intensity is re-estimated at VIII in the MSK intensity scale and covers Constantine and its close surroundings, an area about 600 square km. This earthquake is classified as a moderate and shallow event with a focal depth of about 10 km. The macroseismic epicentre was located near Constantine, at 36.409°N, 6.605°E. The surface-wave magnitude of the main shock was calculated, without station corrections, at 5.25 (± 0.10).

1. Introduction

Constantine, the capital and the largest town in Eastern Algeria, usually a centre of routine domestic life became, abruptly, a place of panic and terror.

On 4 August 1908, at 2 h 11 min (GMT), a destructive earthquake struck the town of Constantine and its surrounding villages and douars. According to the seismic history of the Constantine region reported by Rothé (1950), this seismic event was by no means an exceptional earthquake. The main shock, which lasted about 10 s, and its aftershocks, caused the loss of about 12 lives, injured several and destroyed numerous houses, farms and important buildings. It caused severe damage, particularly to the civil and military hospitals, the Lycée, the cathedral, the theatre, the covered market, the military club, the school house, the Zouave barracks and many more old buildings. The cost of damage was estimated, by the French administration, at 400000 French Francs. The earthquake occurred without any premonitory sign but was followed by a series of aftershocks with one aftershock of magnitude comparable to the main shock. The earthquake was recorded in many seismological stations, up to Tiflis (U.R.S.S.) and Helwan (Egypt). The shaking was felt as far west as La Calle (175 km away) with intensity V^+ (MSK). Maximum intensity reached VIII (MSK) in Constantine and its close surroundings and covered an area of about 14 km radius. The earthquake caused widespread damage in the Constantine area, mainly associated with the high vulnerability of certain types of construction. Because of the time of the occurrence and the poor-quality of the buildings, the earthquake trapped many people under the ruins of their homes. The earthquake was associated with a 200 m long and 50 cm wide ground surface fissure, which was observed in the Plateau of Mansourah. It was reported that all springs, usually cold, suddenly became hot and the thermal springs changed colour to blood-red, which caused fear and panic to the native people. After analysis of the severity of damage caused to the different parts of the affected region, the macroseismic epicentre was located north of Constantine at 36.409°N, 6.605°E. Using teleseismic readings from 4 recording seismological stations, the surface-wave magnitude is calculated, without station corrections, at 5.25 (± 0.10).

2. Sources of information

In order to reconstruct the macroseismic field of this earthquake, a comprehensive search for documents relative to this seismic event was conducted in various libraries and archive centres. The macroseismic information was mainly retrieved from the contemporary press. The most extensive description is given by the «Gazette de France» (1908) which contains very detailed information about the damaged buildings, houses and farms; it even specifies names of the most severely affected buildings, streets, villages and douars. The epicentral area is relatively well described by the different contemporary sources available. In spite of its significance, however, there is, surprisingly, no full report of this event that is well known. In 1932, Sieberg (1932), without quoting his source of information, published an isoseismal map of the earthquake and assigned an intensity VIII (MS) to the region of Constantine (fig. 1). Rothé (1950) briefly summarized the effects of the event using Sieberg and the press as his source. Karnik (1969), quoting the publications of the BCIS, Grandjean (1959) and Sieberg (1932), allocated maximum intensity at VIII (MSK) to the most severely damaged area. Mezcua and Martinez (1983), referring to IPGA, assigned maximum intensity at VIII (MSK). Despite its size, the earthquake was not reported by Gutenberg (Gutenberg and Richter, 1954). We found no evidence that a teleseismic study was carried out for this event. The macroseismic epicentre was located at 36.4°N, 6.6°E by Rothé (1950) who is copied by the later authors Karnik (1969) and Mezcua and Martinez (1983). The magnitude was calculated at 5.1 by Grandjean (1959) and M_S = 5.2 by Karnik (1969).

3. Damage and casualty distribution

The macroseismic information extracted from all the sources available to us have been used in the re-assessment of the effects on the affected region of this event. A detailed study of the macroseismic field has led to a comprehensive re-evaluation of how much damage was caused to man-made structures and to the ground itself, and how the population behaved. As in past earthquakes in Algeria and elsewhere, adobe, stone and mud houses, which were predominant at that time, suffered heavy and/or total destruction. All the sources of information concentrate on the destruction and serious damage in the town of Constantine and its close villages and douars.

In Constantine itself, the whole population was abruptly awakened at 2 h 11 min (GMT) by the shaking. The main shock, which lasted about 10 s, provoked general panic. In fact, people were so frightened that they jumped from their beds and fled their homes, hardly dressed, to the streets and public gardens. Besides the old houses, which were completely destroyed, several important public buildings were heavily damaged and threaten of collapse. The theatre suffered a severe loss of height and it was divided into two clear and distinct parts. In the civilian hospital the patients, terrified by the fall of ceilings and walls, fled from their beds to the garden. In the military prison the prisoners, seeing the walls cracking and crushing down, were

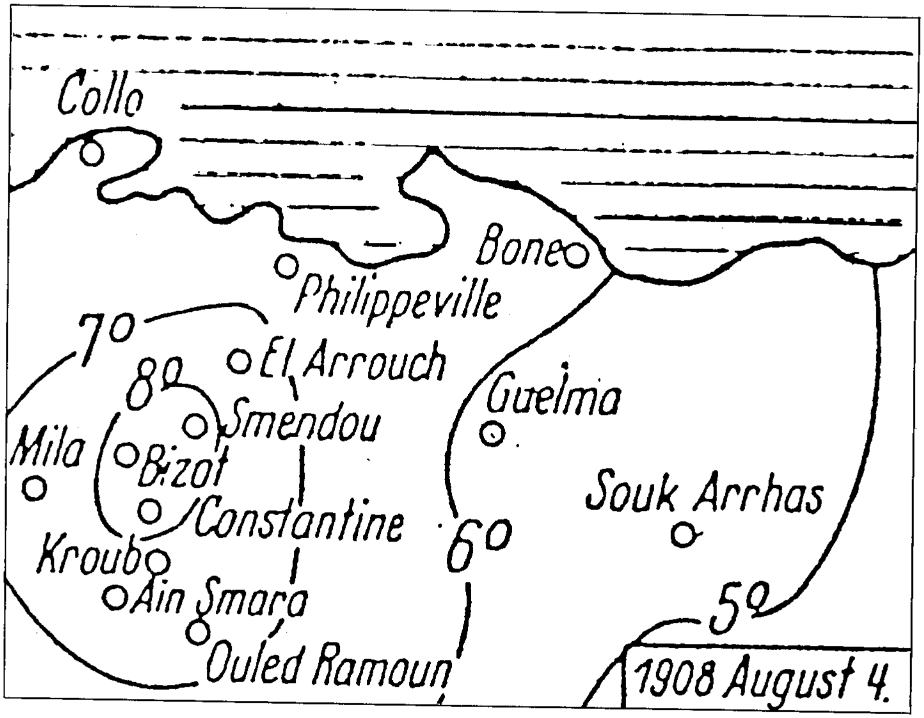

Fig. 1. Isoseismal map (MS scale of the main shock of the Constantine earthquake of 4 August 1908, after Sieberg (1932).

heard screaming in their cells. The Zouave barracks, the military hospital and the Lycée were particularly severely damaged; the cost of damage to these three edifices was estimated at 30000 French Francs. The military hospital had to be evacuated completely and hutted camps were installed for the patients. The cathedral, the covered market, the government controlled building society building (hotel de crédit foncier), the military club and the college of education (école normale), which were poorly built, sustained heavy damage. Particularly, in the college of education, the main wall which forms an arch was separated by about 4 cm from the rest of the construction along 6 m long (Vogt, 1993). This occured despite the strong anchor which was partly damaged, but surely had prevented the wall to collapse (Vogt, 1993). Only cracks were observed on the facades of the apartment buildings but everything was turned upside down inside the flats where many people were trapped under the debris. As an example, in Ledru-Rollin Street, an old lady was buried under the ruins of the ceiling, bricks and furniture of her home. It was reported that she suffered quite painfully in the course of her rescue from the debris. In the native Algerian quarter where 3 native corpses were drawn from the rubble of their homes, most of the houses were heavily damaged and were in serious danger of collapse. In the army barracks called «Quartier des Chausseurs d'Afrique», in Mansourah, several sections of walls crashed down and all the tiles in the area fell to the ground, injuring five persons. In Rouffach few houses were slightly cracked. In Sidi Mabrouk the old school house (maison d'école) was completely destroyed, burying a five year old child who, fortunately, was pulled from the ruins of the building. It was reported that numerous old traditional houses (gourbis) collapsed completely but no details were communicated. Many douars surrounding the town of Constantine were described as an accumulation of ruins. It was reported, without any further detail, that many deadly accidents occurred in the city itself and in the most severely damaged sites. In certain quarters of the town, several chimneys collapsed, the archs of the town hall and the mosque were slightly fissured (Vogt, 1993). In the Faubourg Saint-Jean and El Kantara, walls and ceilings collapsed and the facades of many houses were seriously cracked. It was also reported that the insides of these houses were in ruins (Press, 1908). Twelve kilometres northwest of Constantine, in the Bizot area, and particularly in Ksar El Kellel, five native persons (a mother and her four children), out of a family of seven, were killed and two seriously injured by the collapse of their house. In Bizot itself, several other houses were fissured and some chimneys collapsed (Vogt, 1993). In Conde-Smendou major damage was observed and many people were trapped under the rubble of buildings (Press, 1908) but unfortunately, the details were not published. In Conde-Smendou, the farm of a rich settler (Theolier) was completely destroyed. By a miracle, as reported, the inhabitants of the farm were not all killed. The natives Algerians were less fortunate: four were killed and several injured, though no details were communicated. In El Arrouch, 37 km northeast of Constantine, the main shock, which lasted about 20 s, was so strongly felt that the whole population had to flee from their homes to the streets. In the hospice buildings, several walls, particularly in the nurses rooms, were seriously cracked. In the Plateau of Mansourah the earthquake produced a 200 m long and 50 cm wide ground surface rupture. In Ouled Rahmoun and Kroub the damage was reported as enormous, but no detail was communicated. It was reported that all the springs of the area, which usually are cold, became suddenly hot, whereas the thermal springs changed colour to blood-red. In Philipeville, 65 km north of Constantine, the main shock, which lasted 8 s, was strongly felt and caused a general panic in the area. It was reported that all the population fled their homes to the streets, the marketplace, the wharf and the beach. No damage or casualties were reported. In Bone, 120 km northeast of Constantine, the main shock lasted about 6 s. It was reported that the population sustained only the discomfort of being abruptly awakened and in panic people had fled from their homes to the streets, but the earthquake did not cause any significant damage in the area. In Hamma and Ain Kerma the damage was slight (Vogt, 1993). In Guelma, the shaking was certainly strong, but only the bells were reported to have rang (Vogt, 1993). In Ain Smara, the shock was seriously felt but caused only few cracks in old walls (Vogt, 1993). In Mila, few ceilings and few walls already fissured sustained some damage (Vogt, 1993). It was also reported that in Taher, a small village around Mila, no damage was observed (Vogt, 1993).

In a seismological point of view, it is of interest to mention this note: «a column has overturned around itself a bout a half circle».

4. Intensity re-evaluation

All the macroseismic information retrieved from the different sources available to us, were carefully analyzed and used in the re-evaluation of intensities with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale. This event showed that the Algerian constructions, particularly in the rural zones, were highly vulnerable. As in past earthquakes in Alge-

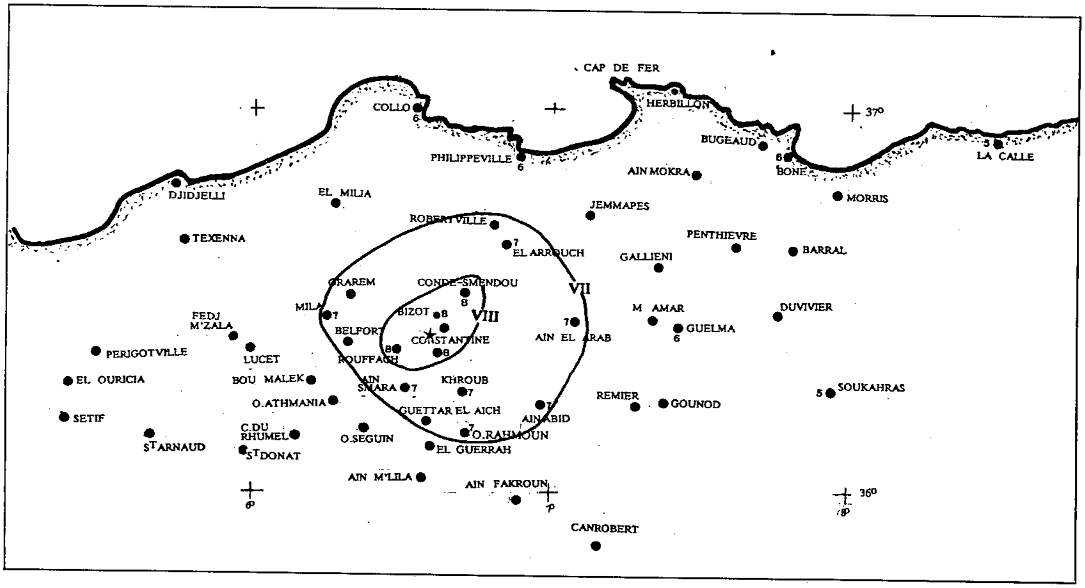

Fig. 2. Isoseismal map (MSK scale) of the main shock of the Constantine earthquake of 4 August 1908. The star shows the macroseismic epicentre of the main shock.

ria and elsewhere, we remarked the ease with which the traditional buildings were destroyed and/or badly damaged. As a consequence of the defectiveness of these constructions, the maximum intensity in destructive earthquake appears to be the same. That is, at intensity IX on the MSK scale, all the traditional houses (gourbis) are totally destroyed and any village would thus look equally, but no more, devastated at higher intensities of the scale.

After much consideration of the macroseismic data collected, maximum intensity was re-evaluated at VIII (MSK) and allocated to Constantine, Sidi Mabrouk, Bizot, Rouffach, Conde-Smendou, Farm Theollier, and Faubourgs Saint Jean and El Kantara. This intensity was attributed to the sites where great damage and loss of life were recorded. Intensity VII was assigned to El Arrouch, Ain Smara, Kroub, Ouled Rahmoun and Mila. Intensity VI was confined to Phillipeville, Collo and Guelma. Intensity V was allocated to Bone and Souk Ahras. Intensities VI to VII were attributed where significant to slight damage was observed. Intensity V was solely assigned on the effects of awakening and panic. As a result of the analysis of the reconstructed macroseismic field, an isoseismal map has been drawn and shown on fig. 2.

5. Magnitude determination

We have calculated the surface-wave magnitude of this earthquake from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 4 seismological stations at distances between 13° and 25°, and a preliminary epicentre at 36.409°N, 6.605°E (macroseismic epicentre). The data and the results are given in Benouar (1993). The mean period is 16 s and the derived value of M_S, without station corrections, is 5.25 (± 0.10).

6. Foreshocks and aftershocks

We found no reports of premonitory observations except one on 18 July in Constantine between 00 h 30 min and 00 h 45 min which was strongly felt by the inhabitants which were shaken in their beds (Vogt, 1993). It was followed by other shocks at about 1 h and 8 h (Vogt, 1993). On the other hand, the main shock was followed by about twenty aftershocks and with one (5 August at 21 h) of equivalent size. Other aftershocks of less intensity were seriously felt on 5 August 1908, in Constantine and its surroundings, causing a tremendous panic at 3 h, 4 h, 7 h 5 min, 7 h 50 min, 12 h 50 min, 14 h 5 min, 16 h 48 min, 17 h 7 min, 17 h 19 min, 17 h 27 min and 18 h 6 min. The largest aftershock occurred on 5 August 1908 at around 21 h (GMT) causing a general panic in the whole of the affected area. The population fled their homes to the streets, the public gardens, the route of Batna and the avenue of the two squares, looking for a safe shelter (Press, 1908). It was reported that the mayor, by common agreement with the military and administrative authorities of the Department, decided on the opening of the two large squares in the city, so that people could camp there for the night. Also aftershocks were reported on the 6 August at 00 h, 2 h 10 min 5 h (slight). New aftershocks were reported in the night of 6 to 7 August particularly at about 20 h 15 min, 12 h 00 min and 3 h 20 min (Vogt, 1993). Except confusion of dates, other aftershocks were reported in the night of the 8 and 9 August at about 20 h and 2 h 30 min (Vogt, 1993). The continuous shaking seriously undermined the spirits of the population, who refused to return to their homes for several days. Thousands of people, as reported, camped in the squares all night long, in spite of a significant drop in temperature, and the cafes were allowed to stay open for the night. No aftershock was reported the 10, but on the 11 August, more strong enough shocks occured with underground rumbling and caused some panic (Vogt, 1993).

7. Discussion

The 4 August 1908 earthquake is the first felt and recorded destructive seismic event in Constantine and its region. In terms of the history of Algeria, Constantine has always had an important role in the Maghreb and thus should have a long and well recorded history, going back to the 3rd century BC. Previous earthquakes of magnitude equivalent to or greater than the 1908 event are reported to have occurred in the region in the past (Chesneau, 1892; Rothé 1950). The earliest event reported was in January 1758 (which needs more research), when the majority of the houses were destroyed and thousands of people died under the rubble. Because of the increase in evaluating seismic hazard and risk in this region, which is one of the most densely populated and industrialized zones in Algeria, it is imperative that extensive search of the cultural background should be carried out, in order eventually to reveal earlier destructive events, and thus extend the time range of seismic activity in the region.

The earthquake caused sufficient damage and casualty to be widely reported in the Algerian, French and International press. The most extensive account is given by «Gazette de France» (1908) which relates in detail the effects of the earthquake as well as the historical context of the period. Press reports are generally rich in detail and constitute an indispensable aid in establishing chronology. These reports, as all other contemporary documents, should be carefully analyzed in the context of the political, socio-economic and demographic conditions, cultural and religious background and building stock characteristics of the period concerned (Ambraseys *et al.*, 1983).

Although it is practically impossible at this stage to assess in detail the effects of the earthquake in each site of the felt zone, from the macroseismic information collected the importance of this event in terms of seismic hazard for the region is shown. Since reports, generally, indicate only significant damage, they are mainly found in the region close to the epicentre. We remarked, for this event, that several intermediate sites (villages, douars and isolated hamlets) within the radius of perceptibility, which could have enriched the data (extensive damage and higher casualty toll), were not mentioned in any contemporary document. In order to estimate the strength of the shaking with an appreciable degree of reliability, a comprehensive search was made to learn what type of buildings existed and in what state they were. It is true that, particularly, the adobe, drystone houses (gourbis), the most predominant type of housing, had already suffered decay through ageing, rain, earthquakes and, particularly, neglect and lack of proper repair. Collection and critical analysis of the reconstructed macroseismic field has led to a detailed re-evaluation of how much damage was caused to human, man-made structures and to the ground itself. The relatively high casualty rate and extensive damage are mainly due to the time of occurrence (people caught asleep) and the poor-quality of the buildings. It is of interest to mention that the casualty toll and the extent of damage were not officially communicated. From the press (1908), we recorded 12 people killed and several injured, all of them native Algerians. We believe that the exact casualty rate may never be known, as many victim were immediately buried after the earthquake to conform the Islamic law, and their deaths were either not reported, simply left out or neglected by the army and/or the administrative authorities. The problem of the information about the native population is discussed in section 1. Chapter I. In spite of the heavy damage caused to many important public buildings, no European is reported even to have been injured, which seems very doubtful.

Summarizing the results, we obtain the following final data for the 4 August 1908 earthquake: origin time: 2 h 11 min (GMT); macroseismic epicentre at 36.409°N, 6.605°E; focal depth: about 10 km; maximum intensity: I_0 = VIII (MSK); magnitude: M_S = 5.25 (± 0.10).

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The Aumale earthquake of 24 June 1910

Abstract
This work presents the largest felt and recorded earthquake in the eastern limits of the Biban Ranges. The Aumale earthquake of 24 June 1910 occurred at 13 h 27 min 1 s (GMT); it represents the strongest felt and recorded seismic event in the Aumale region. This event is the third largest shock in Algeria this century, after the Orléansville 1954 and El-Asnam 1980 earthquakes. The main shock, which lasted between 8 and 10 s, caused the loss of at least 81 lives, injured several and made numerous people homeless; it destroyed or heavily damaged several traditional local dwellings (gourbis), colonial houses and public buildings. The earthquake was widely felt in Algeria; according to Angot, the zone of shaking was limited to the east towards Setif, to the south towards Bou Saada and to the west towards Orléansville. The main shock affected structures at distances of 60 to 100 km. We could find no indication of any sign of ground deformation, except for small fissures in a vineyard in Cheragas. It seems that the earthquake occurred without a foreshock, but on the other hand, it was followed by a long series of aftershocks, continuing until January 1911, with one strong enough to cause further damage. The main shock was recorded by almost all the seismological stations operating at that time. The instrumental epicentre has been relocated, using the present ISC location procedure and readings from 22 stations, at 36.30°N, 3.70°E. The surface-wave magnitude has been computed, without station corrections, at 6.6 (± 0.3). Compilation and critical study of the contemporary documents relative to this earthquake have led to the reconstruction of its macroseismic field and to the re-assessment of the strength of the ground shaking. Intensities have been re-evaluated at 61 sites; maximum intensity has been re-estimated at I_0 = VIII in the MSK scale, assigned to Masqueray, Ouled Dahmane, El Arba, Ouled Meriem, Sidi Saad, Douar El Euch and Les Trembles, an area of about 16 km radius. From the intensity data, a macroseismic epicentre has been located at 36.230°N, 3.437°E and an isoseismal map has been constructed. It seems that no official evaluation of the casualties among the population or damage has been carried out. We could find no report of any relief operation or financial help to the victims.

1. Introduction

On Friday 24 June 1910, at 13 h 27 min 1 s (GMT), a large earthquake struck the region of Aumale. The epicentral region is located, at about 80 km southeast of the capital Alger, on the Titteri Mountains. According to the seismic history of the region reported by Hée (1933 and 1950), Rothé (1950) and Mezcua and Martinez (1983), the region of Aumale has experienced several destructive earthquakes these two last centuries, thus this event was by no means unprecedented. The main shock, which lasted between 8 and 10 s, caused the loss of at least 81 lives, injured several and made numerous people homeless; it destroyed several traditional local dwellings (gourbis), colonial houses and public buildings. The epicentral zone, within which the shock caused heavy damage and loss of life, was somewhat isolated and sparsely populated. According to Angot (1910), the limit of the shaking seems to have been as far east as Setif, south as Bou Saada and west as Orleansville, but he is not precise as to the shock was actually felt in these sites. The main shock affected structures, with intensity V^+ (MSK), within distances of 60 to 100 km. It apparently seems that the earthquake occurred without a foreshock, but it was followed by a long sequence of aftershocks, continuing until January 1911, with one strong enough to cause additional damage. We could find no indication of any sign of ground deformation in the affected region, except for small fissures in a vineyard in a farm in Cheragas. The main shock was recorded by almost all the seismograph stations operating at that time. The instrumental epicentre has been relocated, using the present ISC procedure, at 36.3°N, 3.7°E. The surface-wave magnitude has been computed, without station corrections, at 6.6 (± 0.3).

Collection and critical analysis of the contemporary documents relative to this earthquake have led to a detailed re-evaluation of how much damage was caused to man-made structures and to natural features and how the population behaved during the shaking in the affected region. As in past destructive earthquakes in Algeria and elsewhere, adobe, drystone and unreinforced masonry structures sustained total collapse or heavy damage. The macroseismic information retrieved from the available sources have allowed us to re-estimate intensities in 61 different sites. After a careful analysis of the data, maximum intensity has been re-evaluated at I_0 = VIII in the intensity MSK scale, allocated to Masqueray, Ouled Dahmane, El Arba, Ouled Meriem, Sidi Saad, Douar El Euch, Les Trembles and their immediate vicinities, an area of about 16 km radius. From the intensity data, a macroseismic epicentre has been located at 36.230°N, 3.437°E and an isoseismal map of the main shock of 24 June 1910 earthquake has been drawn. It seems that no official evaluation of casualties among the population or extent of damage was carried out. Despite the scope of damage recorded, we could find no report of any relief operation or financial help to the victims from the administration.

2. Sources of information

An extensive search for contemporary documents relative to this earthquake has been carried out in many libraries and archive centres in order to reconstruct its macroseismic field with an appreciable degree of reliability. The result of this investigation is a collection of Algerian and French newspaper reports, scientific studies, private diaries and instrumental data from seismological station bulletins. Among the press reports, the most comprehensive account is given in «La Dépêche Algérienne» which contains detailed macroseismic information. It has brought together details about earthquake effects, animal and human behaviour, as well as casualties among the population. Despite its significance in Algeria there is, surprisingly, only one complete scientific study of this event that is really known: that is the work by Ambraseys *et al.* (1991a). Their report presents a detailed re-evaluation of the effects of the earthquake, a relocalisation of the instrumental epicentre and computation of surface-wave magnitudes of the main shock as well as for the two largest aftershocks. They published an intensity distribution map of the main shock (fig. 1) as well as for the largest aftershock (fig. 2). However, the effects of the earthquake were first briefly described by Migot (1910) and summarized by Angot (1910). Migot proposed that the macroseismic epicentre should be in the vicinity of Aumale, about 70 km southeast of the capital Alger, where loss of life and maximum damage were recorded. Later authors (Hée, 1950; Sieberg, 1932 and Rothé, 1950) have used Migot (1910) as their macroseismic information source. However, Sieberg (1932), without quoting his source of information,

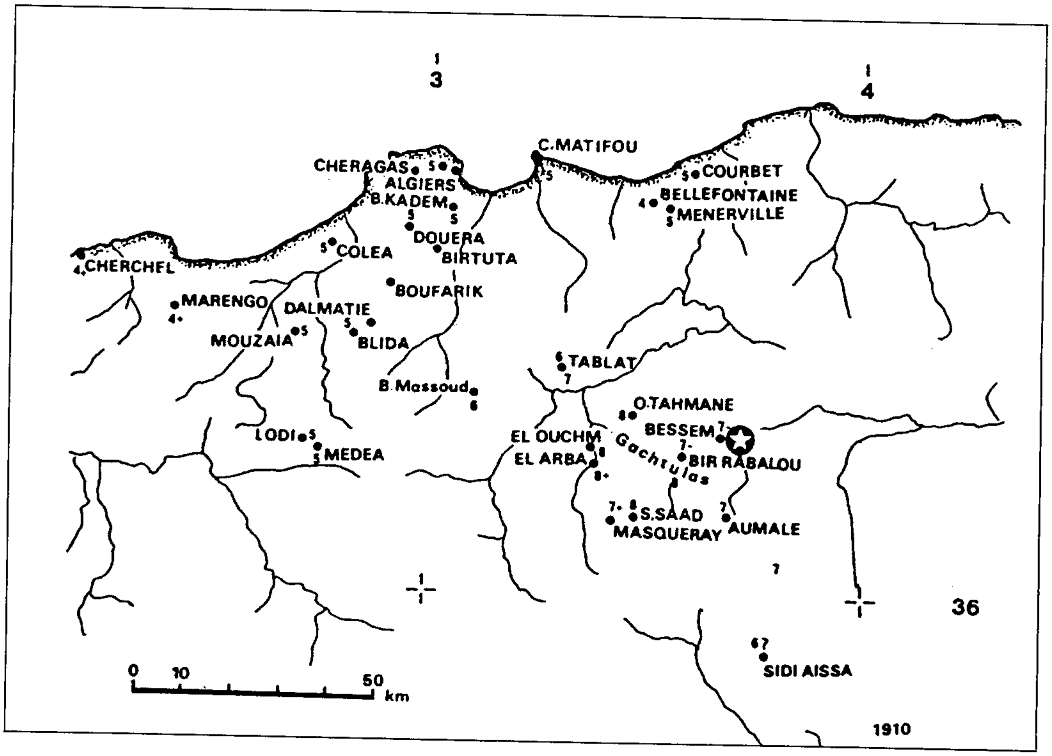

Fig. 1. Intensity distribution (in terms of MSK scale) of the main shock of the 24 June 1910 Aumale earthquake, after Ambraseys *et al.* (1991a).

published an isoseismal map of the main shock (fig. 3) as well as that of the 7 January 1911 aftershock (fig. 4). He attributed maximum intensity of XI (MCS) to the region of Masqueray. The instrumental study of this earthquake had been conducted first by Milne (1913) at 36°N, 4°E. This epicentre location was adopted without any further computation, on the evidence of damage observations near Aumale, reported by Angot (1910). Later, Gutenberg and Richter (1954) carried out a teleseismic study of this earthquake. Their solution did not make any change to the original macroseismic location advised by Milne. Gutenberg estimates the magnitude of this earthquake at 6.4. Munuera (1963) suggested an epicentre at 36.2°N, 3.4°E and assigned a maximum intensity at XI (MS) and a magnitude of m_b = 7.5, without quoting his information sources.

In the recent catalogues, other authors have also reported the event. Karnik (1969) assigned an intensity of X (MS) and calculated a body-wave magnitude at m_b = 6.6. Mezcua and Martinez (1983) attributed a maximum intensity at XI (MSK), a magnitude m_b at 6.4 and an epicentre at 36.050°N, 3.416°E, quoting SSIS as their source.

3. Geographical aspects of the region

The epicentral zone is located in the central part of the country at about 80 km southeast of the capital Alger. It lies on the northern flank of Djebel Dira (1810 m) in

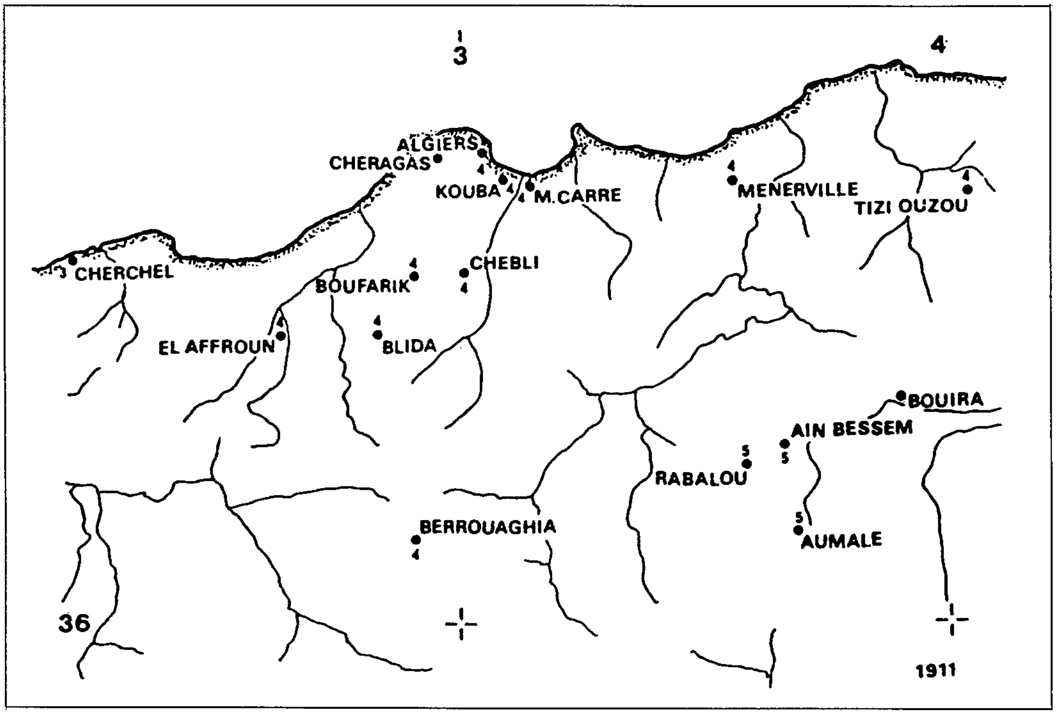

Fig. 2. Intensity distribution (in terms of MSK scale) of the largest aftershock of 7 January 1911, after Ambraseys *et al.* (1991a).

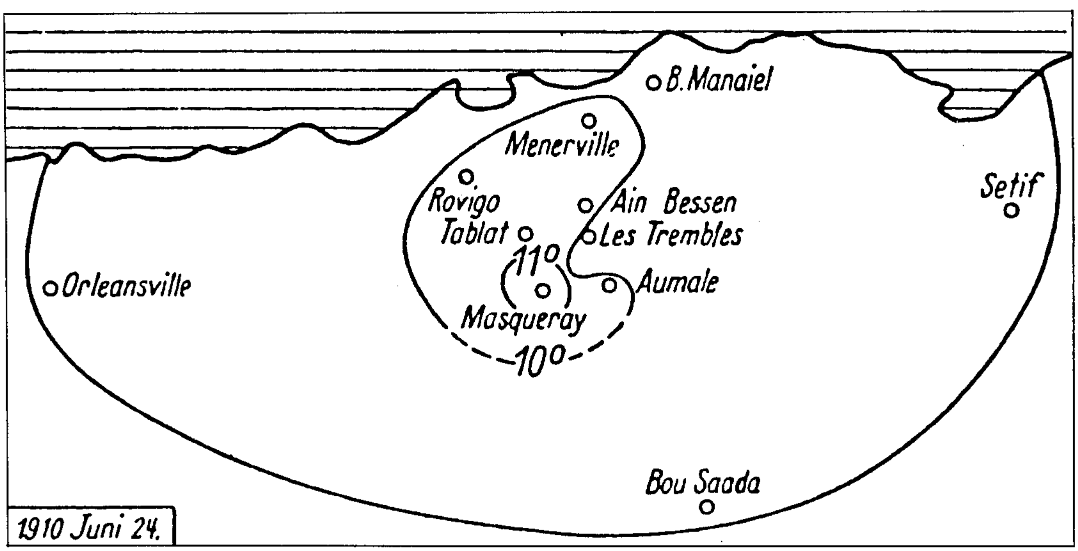

Fig. 3. Isoseismal map (in terms of MS scale) of the main shock of the 24 June 1910 Aumale earthquake, after Sieberg (1932).

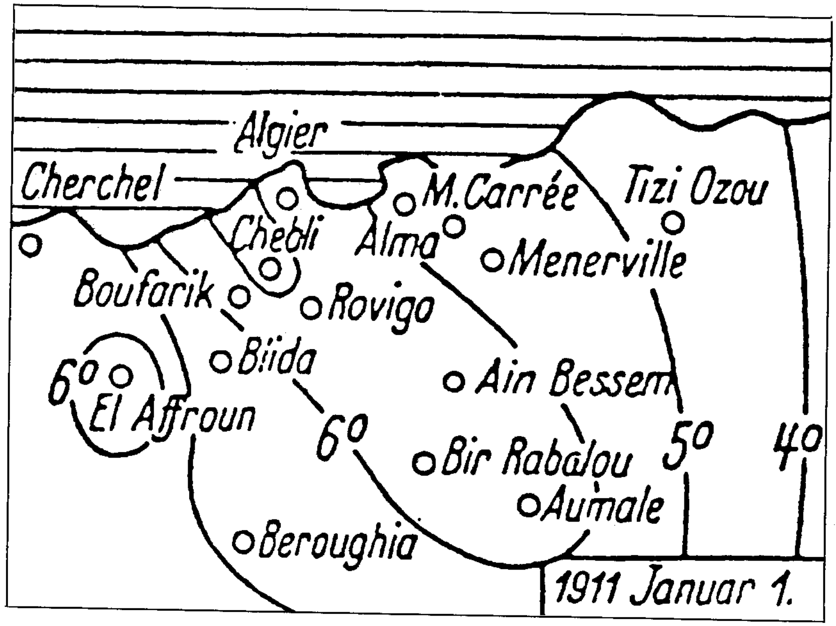

Fig. 4. Isoseismal map (in terms of MS scale) of the largest aftershock of 7 January 1911, after Sieberg (1932).

the eastern limits of the Biban ranges. This massif forms, from the north to the southwest, an arc of a circle which is limited, to the west, by the Djebel Kef-Lakhdar (1464 m); it separates the Tell mountains and the High Plateaux. Aumale, which was called Auzia during the Roman empire, was founded during the Augustan reign, few years before the Christian era; the Turks have built a fortress and called it Sour El Ghozlane (in Arabic: wall of the Gazelles) (Fillas, 1884; Gsell, 1929). During the French colonization period, it was used as an important military post. Aumale was also the chief town of the «Commune mixte» of 30000 inhabitants and of a native city of 20000. According to the history of Algeria, the region of Aumale has always been an important site and therefore should have a long and well recorded history. Careful research into the cultural background of the region would certainly reveal many previous destructive earthquakes of magnitude equivalent to, or greater than, the 1910 earthquake.

4. Damage and casualty distributions

It would appear that the earthquake occurred without a foreshock, at 13 h 27 min 1 s (GMT). The main shock, which in the epicentral zone lasted between 8 and 10 s, killed at least 81 people, injured several and made numerous people homeless; it destroyed or heavily damaged many traditional local houses (gourbis), colonial houses and public buildings. The shaking was widely felt in Algeria and affected structures, with intensity V^+ (MSK), at distances of 60 to 100 km (fig. 5). We could find no report of any ground deformations, except for a few small fissures in a vineyard in Cheragas. Most of the sources available to us confirm the destruction in the region between Tablat and Bir Rabalou, as well as in the plain of Gachtulas where numerous traditional local douars were totally destroyed and hundreds of native Algerians lost their lives. Several douars in the surrounding mountains experienced heavy damage but, unfortunately, details are missing. It was reported that about 30 people were killed in Ouled Dahmane, 12 in El Arba, 12 in Douar El Euch and 27 at Ouled Meriem (already destroyed in 1886), an area in the vicinity of Souk El Arba.

In Aumale, a small colonisation village located at 90 km southeast of the capital Alger, the shock was strong enough to cause a great panic among the population. The people, most of which were sleeping, were suddenly awakened and fled from their houses in very light clothes. Women and children ran screaming from their homes into the streets. The main damage consisted of the collapse of the Court building (Salle de la Justice de Paix) which is next to the City Hall, the destruction of the roof of a café breaking all the objects inside, collapse of the roofs of the military shops, as well as the walls of a building in the army barracks. Fearing other strong shocks, the troops were reported to be camping in the open for few days. More damage was reported to have been observed in the town, but details were not communicated. A wall of a big house, in collapsing, crushed the roof of a contiguous small dwelling, burying an 85 year old man. The minaret of the Mosque was on the point to collapse. All the pendulum clocks stopped at 13 h 30 min (GMT). The extent of the damage caused people to camp in

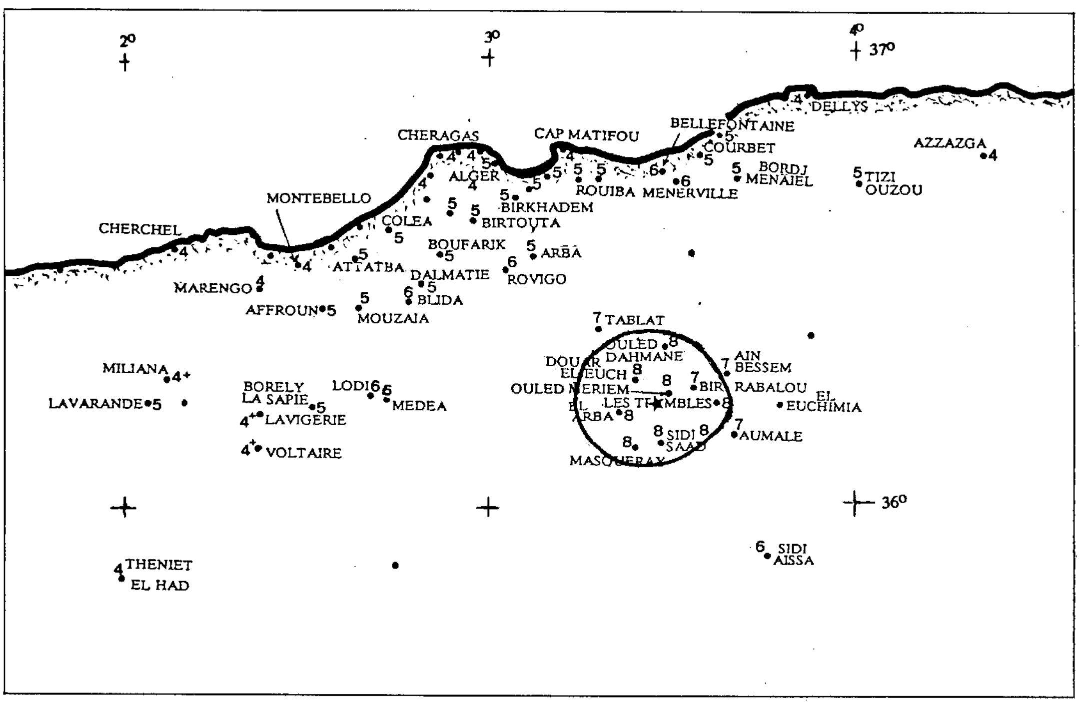

Fig. 5. Isoseismal map (in terms of MSK scale) of the main shock of the 24 June 1910 Aumale earthquake. The star shows the macroseismic epicentre.

the streets. Twenty five kilometres east of Aumale, in Masqueray, a village founded in 1907, the earthquake was strong enough to damage all the European houses, including the school and public buildings, to the extent that many had to be evacuated and two people were reported injured. Three kilometres from Masqueray, the forestry house, which was relatively well built, collapsed completely and buried three people under its debris. Along the road between Masqueray and Aumale, many local houses and the marabout Sidi Saad were razed to the ground. In this area, the bridge on the Oued Zeroua was seriously damaged and the valley blocked by enormous rockfalls, which also caused a blockage in the road. In Bir Rabalou, a small village located at about 20 km northeast of Masqueray, the shock was violent enough to destroy chimneys, ceilings and free-standing walls, as well as all the European houses where some people were reported injured. A further 9 km northeast, in Ain Bessem, the main shock, which lasted between 8 and 10 s, was strongly felt. The population, in a panic, rushed out from their houses and public buildings; many of them were reported running in the streets, in their night clothes, looking for their children in the schools. Many women disappeared. All the inhabitants spent the night in the open, camping in the gardens surrounding their houses for fear of larger shocks. Most damage in this village consisted of the collapse of large sections of the walls of public buildings and bricks, tiles and chimneys thrown violently to the ground. Most houses in the village were fissured. The fronton and a large section of the administrator house were destroyed, the walls of the post office were seriously damaged, as well as most of the public buildings. One shop was so shaken that all the dishes were thrown from the shelves and broken and many other objects were tangled together. The public pendulum clocks had stopped exactly at 13 h 30 min (GMT). Outlying native douars were reported to have suffered total destruction with significant casualties among the population; details, however, are not available. The scope of the disaster caused the village to be evacuated. In the plains of Beni Slimane and Beni Arib, west and east of Bir Rabalou, not a single man-made structure was left undamaged, and roadside houses were completely shattered. Thirty five kilometres northwest of Ain Bessem, in Tablat, most of the damage consisted of cracks in the majority of buildings. The roof of a moorish café collapsed, injuring a native. Remote native douars and settlements to the south of the village experienced heavy damage with casualties among the population, but the information in the press reports are confusing. The douar El Euch (city of Tablat) suffered particularly, with many people reported killed, but specific details are lacking. In Les Trembles, a small colonisation village located between Aumale and Bir Rabalou, damage to structures was reported to be major, but no details were given. In Lodi and Medea the shaking, which lasted about one minute during two consecutive shocks, caused some panic among the inhabitants. The population was terrified as many people, who were asleep, were brutally awakened and fled, half dressed, into the streets. In Lodi the steeple clock stopped at 13 h 33 min 30 s. It is reported that during the shaking, water in the open reservoirs was seen pouring out from one side then from the other, and some people, dazzled by the rhythmic dance of the trees, had lost their balance and had to sit on the ground. Further north, in Blida, a town located at 85 km northwest of Aumale, the main shock, which lasted about 12 s, caused serious panic among the population, particularly in high-rise structures. Many people, panic-stricken, fled their houses to the streets. The furniture in most houses were displaced, steeple bells of the Saint-Charles church had rung. Most damage consisted of cracks in ceilings. North of Blida, in Beni Mered, the shaking, of which the duration was about 8 s, was so strong that the inhabitants had precipitately left their houses. Only some furniture was reported displaced and the pendulum clocks stopped. No casualties were reported among the population. In the colonial village of Borey-La-Sapie the shock was strongly felt and lasted a few seconds. In spite of the violence of the shaking, no damage was recorded. The population was seriously alarmed and fled to the open. In Boufarik, two shocks were felt in a two minute time interval, of which the duration of each one was about 3 s. The population rushed from their homes to the streets. No damage was observed. In El Affroun two consecutive shocks were seriously felt by all the inhabitants, causing significant concern. A few ceilings were cracked and objects hung on the walls were thrown to the ground. Further east, in Theniet-El-Had, the shaking, which had a duration of 5 s, was strongly felt. The oscillations were from east to west. In Miliana a strong shock, which lasted about 10 s, was strongly felt by the population. In Lavarande the main shock was strong enough to cause scores of families to flee from their dwellings to the streets. The public pendulum clock stopped during the shaking. In the village of Voltaire the shock was felt in the settlement and its vicinity, but neither damage nor casualties among the inhabitants were reported. In Lavigerie and Attatba the main shock, which lasted about 20 s, was accompanied by intense underground rumbling. The earthquake was seriously felt by the whole population, and caused some panic but neither damage nor casualties. The most remarkable phenomenon during the shaking was that all the pendulum clocks had stopped. In Montebello a strong and long shaking was felt at about 13 h 35 min but no damage occurred. In Menerville the earthquake was seriously felt. It caused severe damage to the girl's school, the court buildings (Batiments de la Justice de Paix) and the civil hospital buildings which suffered most. Fortunately, despite the damage caused, there were no casualties. It was strongly felt in Bellefontaine, where it lasted about 4 s, and caused some concern among the population. Numerous people, who were asleep, were abruptly awakened by the violence of the shock. Several houses were cracked, the steeple bell rang and the pendulum clocks stopped running. It was in the school that the emotion was highest. The children, already alarmed by the shaking, were terrified when large sections of the ceiling plaster, which was old and in a bad state, suddenly collapsed. The children, panic-stricken, fled from the classrooms to the playgrounds, but no casualties were observed. In Figuier, an account reported: «...several fishermen resting on the beach, near a rock overhanging the sea, when the earthquake struck; the commotion was so violent that they believed that the big rock was shaking and threatening to fall on them In a panic, they fled the site leaving all their belongings behind them». Northeast of Masqueray, about 85 km northwest, in the village of Tizi Ouzou, the shock of which the violence was particularly observed in the upper part of the town was strongly felt. The duration of the shaking was more than 20 s. In certain houses built on basements, the noise was so intense that the inhabitants rushed out to the streets. During the shaking, the bells of the town hall rang. Numerous cracks were recorded in the ceilings of several buildings. In the village of Azzazga a strong shock was felt but no damage was reported. Thirty kilometres northwest of Tizi Ouzou, in Dellys, the shaking, which lasted 8 s, was strongly felt in the village and its immediate vicinity. The main shock lasted more than 20 s in Bordj Menaiel where it was strong enough to make the inhabitants flee their homes. Most damage consisted of fissures in walls and ceilings. In Courbet, a small village located at 75 km northeast of Masqueray, the shock was strongly felt and caused significant panic among the population which fled to the open. Damage, not major, consisted mainly of cracks in some houses. Clearly felt in the Arba region, the earthquake, which lasted about 8 s, did not cause any damage. In Rovigo the earthquake had a duration of 6 s and was preceded by an underground rumbling. Several chimneys collapsed and a newly built house, on the main street, had its west gable wall heavily cracked the upper part. The steeple clock, as well as many other pendulum clocks, stopped at 13 h 35 min and 13 h 40 min. The main shock, which lasted about 4 s in Rivet, was felt by all the inhabitants of this village and its surroundings, but there was no alarm. In Birkhadem the shaking was felt for a period of 12 s. It caused considerable concern among the population, but no damage was observed. It was strongly felt in Mouzaia-Les-Mines and particularly in the Bordj, but there was no alarm. Further northeast, in Birtouta, the earthquake, which lasted 15 s, was significantly felt. Numerous people were taken by a malaise similar to that caused by a rolling ship. In Dalmatie the water in washing-basins gushed out of the walls, furniture in a few houses was displaced and most of the pendulum clocks stopped. The shock was preceded by a deafening underground rumbling which was like that made by a heavily loaded moving truck. In Camp des Chenes the shaking was clearly felt, but no damage was reported. In Kouba, a 10 s shock was felt, but no damage reported. In the capital Alger, located at 80 km northwest of Masqueray, for more than 20 s, the shock caused real fear among the population in certain quarters. Many of the sleeping people were brutally awakened. In Boulevard Victor Hugo, in a house which was under construction, the workmen were so scared that they hastily descended the scaffolding and were seen running and screaming in terror (press reports, 1910). In the quarter of La Marine (quartier de la marine), numerous fishermen of Italian origin, together with women and children, fled from their homes to the streets. Damage to houses was no more serious than the displacement of furniture and breakage of dishes; however, the water main pipe supplying the capital sustained significant damage. The shaking was felt in the whole Department of Alger where it caused, in certain sites, a veritable panic and serious damage. In Ouled Fayet it was strongly felt in the village and its immediate vicinity. Most of the pendulum clocks stopped. In Douera damage to houses was no more than some slight fissures in certain old walls, but caused considerable concern among the population, which fled to the open. The steeple clock stopped at exactly 13 h 40 min. In Gue de Constantine the earthquake, which lasted about 5 s, seriously frightened the employees of the Borgeaud and Revelin factories and caused them to flee the buildings. The earthquake caused considerable panic among the inhabitants of Maison Carrée and slight damage was reported, though details are missing. Further west in Cheragas, it was seriously felt for about 20 s and caused slight fissures in the farm Liori. At the farm Boyer, in Beni Messous, the bell rang. East of Alger, in Rouiba, the shaking was so strong that many people, frightened, rushed out their homes. In the schools children, also terrified by the shock, had fled the classrooms. Further east, in Reghaia, many people run outdoors. In Fort de l'Eau, a small village located at 7 km east of Alger, across the bay, the shock triggered the start of a panic among the population. Some damage was observed of which details were not communicated. In Cap Matifou the shaking was seriously felt, but no damage was observed.

Late press reports indicate some damage in many other douars on the south side of Djebel Dira, between Sidi Aissa and Aumale, but it is not certain whether the effects correspond to the same main shock or a later strong aftershock.

We found no report of any felt effects of the earthquake from the eastern part of the country or from the south. However, Angot (1910) noticed that: «... the zone of the shaking seems to be limited to the east towards Setif, to the south towards Bou Saada and to the west towards Orléansville». The search continues for additional details of damage and casualties among the population.

5. Intensity re-evaluation

Using all the macroseismic data retrieved from the various sources available to us, intensities in 61 sites have been re-estimated with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale. A careful analysis of the macroseismic information has led to a detailed reassessment of how much damage was inflicted to humans, man-made structures and to nature itself. It is of great importance to mention that the building stock exposed to the shaking was predominantly characterized by adobe, drystone, mud-reed, mud-straw and ordinary masonry constructions. According to certain sources, many of these structures were in an advanced decay state, and suffered through ageing, negligence, rain, earthquakes and lack of proper repair. As a consequence of the defectiveness of these constructions, maximum intensity in any destructive earthquake in the douars and villages would appear to be the same. That is, at intensity IX in the MSK scale, most of the buildings would be totally destroyed and any douar would thus look equally, but no more, devastated at higher intensities of the scale.

After much study of the macroseismic field of this event, maximum intensity has been re-estimated at I_0 = VIII (MSK), allocated to Masqueray, Ouled Dahmane, El Arba, Douar El Euch, Ouled Meriem, Sidi Saad and Les Trembles. This intensity has been assigned to the sites associated with such major damage as collapse of structures and loss of life. Intensity VII has been confined to Aumale, Tablat, El Euchima, Bir Rabalou, Ain Bessem and the douars south of Tablat. Intensity VI has been attributed to Medea, Lodi, Blida, Menerville, Bellefontaine, Rovigo, Gue de Constantine and Sidi Aissa. Intensity V has been assigned to Beni Mered, Borely-La-Sapie, Boufarik, El Affroun, Lavarande, Attatba, Tizi Ouzou, Figuier, Bordj Menaiel, Courbet, Arbaa, Birkhadem, Mouzaia-Les-Mines, Birtouta, Dalmatie, Douera, Alger, Maison Carée, Rouiba, Reghaia, Colea and Fort de l'eau. Intensity IV has been attributed to Theniet El Had, Miliana, Voltaire, Lavigerie, Lavarande, Cheragas, Montebello, Azzaga, Dellys, Rivet, Draria, Kouba, Ouled Fayet, Bouzareah, Cap Matifou, Camp des Chenes, Marengo and Cherchell. Intensities V to VII have been assigned with rigid interpretation of the MSK intensity scale (Medvedev *et al.*, 1981). Intensity IV has been assigned mainly on felt effects and on the evidence of lack of damage to poor-quality structures.

From the intensity data, a macroseismic epicentre has been located at 36.230°N, 3.437°E and an isoseismal map of the main shock of 24 June 1910 Aumale earthquake has been constructed and shown in fig. 5.

6. 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 9 stations located at distances between 6° and 25°, and a preliminary epicentre (macroseismic) at 36.230°N, 3.437°E. 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 6.6 (± 0.3).

We have also calculated the surface-wave magnitude of the main shock from the calibration relation derived by Ambraseys and Melville (1982) for the undamped Milne pendula, using amplitude readings from 19 seismograph stations (undamped Milne pendula) located at distances between 7° and 121°. The details of the data and the results are given in Benouar (1993). The derived value of the equivalent surface-wave magnitude M_S, without station corrections, is 6.6 (± 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 22 seismograph stations which reported the event to the International Seismological Summary (ISS). The main shock was mainly reported by European stations, the closest being Carloforte in Sardinia. Apart from San Fernando (SFS) and Cartuja (CRT) in Spain, and Paris (PAR) in France, which were slightly to the northwest, all other stations are in the northeast from the macroseismic epicentre, resulting in a poor azimuthal distribution of the stations around the epicentre. Stations with large residuals have been weighed small or left out of the analysis. With trial origin consistent with the maximum reported experienced effects (36.2°N, 3.4°E), we find:

1910 June 24
13 h 27 min 1 s (± 1.9)
36.3°N (± 0.17), 3.7°E (± 0.11)
Depth 10 km (assumed).

This position agrees with the macroseismic epicentre with errors of about 8 km in latitude and 29 km in longitude.

8. Foreshocks and aftershocks

It appears that the earthquake occurred without a foreshock, but it was followed by a long series of aftershocks, continuing until 7 January 1911.

Among the largest aftershocks, that of 20 August 1910, which occurred at 1 h 20 min, produced some damage in Aumale and Bir Rabalou, and was seriously felt in Tablat, Blida and as far east as Courbet and north as Alger. This aftershock was largely recorded. Using teleseismic data available and the standard Prague formula, the surface-wave magnitude has been computed, without station corrections, at 4.7 (± 0.20). The largest aftershock occurred on 7 January 1911 at 1 h 33 min, and caused damage in the zone containing Aumale, Bir Rabalou, Ain Bessem, Rovigo and Alger. It was felt from Cherchell in the west to Tizi Ouzou in the east. The intensities derived from the analysis of the macroseismic data, relative to this aftershock, are similar to those assigned by Ambraseys *et al.* (1991a) and shown in fig. 2. The shock was not widely recorded because its occurrence was close to that of a large-distant earthquake (Ambraseys *et al.*, 1991a). However, the teleseismic data relative to this aftershock have been used to calculate the surface-wave magnitude of which the derived value, without station corrections, is 5.1 (± 0.20), employing the same procedure as previously. Figure 4 shows the isoseismal map of this aftershock drawn by Sieberg (1932). This map shows intensities highly different from what can be suggested from data available to us, but it is of interest to mention that Sieberg (1932) did not quote his source of information.

9. Discussion

The Aumale 24 June 1910 earthquake is the largest seismic event felt and recorded in the region this century. It constitutes the third largest seismic shock that occurred in Algeria, after Orléansville (1954) and El-Asnam (1980). In terms of the seismic history of the Aumale region reported by Hée (1933 and 1950), Rothé (1950), Mezcua and Martinez (1983) and Ambraseys and Vogt (1988), it appears that many destructive earthquakes had struck the region in the last two hundred years, and therefore this earthquake is by no means an exceptional one. It shows the potential for a higher degree of time and spatial inhomogeneities of seismicity in the region and the consequences of this in the evaluation of seismic hazard in Algeria.

During this earthquake, as in past destructive ones in Algeria and elsewhere, traditional local dwellings (gourbis) and colonial ordinary masonry houses suffered most damage. The typical habitation structure was built of mud-reed, mud-straw, drystone or sundried adobe bricks covered with a heavy roof which made the whole construction highly vulnerable to earthquake loads. A general conclusion that may be drawn about this type of structure is, therefore, that its inherent strength is very low and variable and its vulnerability extremely high. Thus, as a consequence of the fragility of the building stock exposed to the shaking, maximum intensity in any destructive earthquake in the region would appear the same. That is, at intensity IX (MSK), all traditional local buildings are destroyed and any douar would look equally, but no more, devastated at higher intensities of the scale.

Concerning the limit of the felt area, details from the eastern part of Algeria, from the west and the south are missing. However, Angot (1910) noticed that: «... the zone of shaking seems to be limited to the east towards Setif, to the west towards Orléansville and to the south towards Bou Saada». He does not mention whether the shock was felt in these localities, though we found no proof to the contrary.

For a judicious analytical study of past destructive earthquakes and for better understanding of the information contained in the contemporary documentary sources, it is vital that one should take into account the political, socio-economic and demographic conditions, cultural and religious background as well as the building stock characteristics of the period concerned. The earthquake affected a rather isolated and sparsely distributed population area from which, even nowadays, it would not have been easy to retrieve damage data. Several douars in many intermediate colonial villages and towns within the radius of perceptibility which, according to press reports, suffered major damage, are not mentioned by name. Most of the information in the press was limited to colonial villages and towns in the affected zone. The lack of information about the native Algerian inhabitants was apparently influenced by some neglect of the French administration (see section 1. Chapter I). However, official reports at that time rarely communicated loss statistics for non-European settlements. The real number of victims will be never known since many native Algerian victims, immediately buried to conform to the Islamic law, were either not reported or not communicated by the French authorities. This may explain why property and human losses were disproportionately small for an earthquake of this size in an area of poor-quality construction. The search continues for additional details of damage and casualties in the whole affected area.

Summarizing the results, we obtain the following final data for the 24 June 1910 earthquake: origin time: 13 h 27 min 1 s (GMT); instrumental epicentre: 36.3°N, 3.7°E; macroseismic epicentre: 36.230°N, 3.437°E; maximum intensity: I_0 = VIII (MSK); magnitude: M_S = 6.6 (± 0.3).

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The Cavaignac earthquake of 25 August 1922

Abstract
This research presents the study of the earthquake which occurred in the Orléansville-Tenes region on 25 August 1922. On 25 August, 1922, at 11 h 47 min 24 s, a destructive earthquake struck the Orléansville-Tenes region. It caused severe damage to a small area, of about 20 km radius, where the colonisation village of Cavaignac was the centre. It seems that the earthquake occurred without a foreshock. In other hand, it was followed by many aftershocks. The radius of perceptibility was relatively small; the shaking was felt, with intensity III (MSK), in Alger 170 km east and in Relizane 95 km west of Cavaignac. The earthquake caused at least a loss of 4 lives, injured many others and made a hundred homeless. The village of Cavaignac was reported to be completely ruined. The main shock produced rockfall in and around Cavaignac. The information extracted from contemporary sources are used in the re-assessment of the damage and the re-evaluation of intensities. Intensities are re-estimated at 13 localities. Maximum intensity reached VIII in the MSK scale and covers a small area, of about 7 km radius, around the village of Cavaignac (macroseismic epicentre). Intensity VII (MSK) covers an area of approximately 27 km radius. From the intensity data, an isoseismal map has been constructed and a macroseismic epicentre located, in Cavaignac, at 36.42°N, 1.20°E. This earthquake is classified as a shallow moderate event with a focal depth of about 4 km and a surface-wave magnitude M_S = 5.1 (± 0.3). The teleseismic relocation, using the present ISC location procedure, gives an epicentral relocation at 36.4°N, 1.3°E.

1. Introduction

On 25 August 1922 at 11 h 47 min 24 s, an earthquake severely shook the small region of Orléansville-Tenes causing slight damage to these two cities, but the colonisation village of Cavaignac was completely destroyed. Few seconds after the shaking, the village was looking as a region devastated by war as reported by the local press. Few houses were still standing up over 50 houses existing at that time, but none of them was suitable for use. Although the earthquake ruined completely the village, the number of victims is very small and consists of 4 dead and few injured. The earthquake occurred without any premonitory sign, but it was followed by a sequence of aftershocks.

The shaking was felt over a distance of 270 km from Relizane in the west to Alger in the east of Cavaignac. The most damaged area (of about 20 km radius) was the village of Cavaignac and its surroundings. In the epicentral zone, it was strongly felt and caused much damage in the area containing Cavaignac, Hanoteau, Mentenotte, Flatters and Kalloul. Maximum intensity reached is re-estimated at I_0 = VIII (MSK). From the macroseismic data, an isoseismal map of the Cavaignac 1922 earthquake has been drawn and a macroseismic epicentre determined at 32.42°N, 1.20°E. The main shock was recorded at 24 seismological stations (ISS, 1922). The surface-wave magnitude M_S is calculated at M_S = 5.10 (± 0.3). The relocation of this event using the present location procedure of the International Seismological Centre (ISC) gives an epicentral position at 36.4°N, 1.3°E.

2. Sources of information

An extensive search for contemporary documents relative to this earthquake has been carried out in various libraries and archive centres. This event was relatively well reported by Hée (1923), Brives and Dalloni (1922), Rothé (1950) and also by European and local press. Although no isoseismal map has been constructed, some writers had assigned intensities to some sites around Cavaignac. Hée (1923) attributed an intensity I_0 = IX-X (RF) to Cavaignac which is believed to be the centre of the shaking. She assigned IX (RF) to Talassa, VIII-IX (RF) to Kalloul, VIII (RF) to Mentenotte, Flatters, Chasseriau, Tenes and Hanoteau, VII-VIII (RF) to Fromentin, VI (RF) to Cherchell and Orléansville, II-III (RF) to Relizane and II (RF) to Alger. Brives and Dalloni (1922) attributed an epicentral intensity I_0 = X (RF) to Cavaignac. Also, it was assigned an intensity I_0 = X (MM) by Rothé (1950), X (MS) by Karnik (1969), X (MM) by Ambraseys (1981a) and IX (MSK) by Mezcua and Martinez (1983).

The first instrumental studies of this earthquake were carried out by the Bureau Central de Séismologie de Strasbourg (BCSS, 1922) and the International Seismological Summary (ISS, 1922). The BCSS had determined the location of the epicentre and the original time by using the microseismic data recorded at a certain number of relatively close stations (Alger, Cartuja, Granada, Barcelone, Coimbra, Rome, Zurich, Strasbourg) and Helwan which is of a particular interest because of being on the same continent as Alger. The epicentral location of the event is than given at (36.28°N, 1.26°E), located at about 10 km southwest of Cavaignac and the origin time as 11 h 47 min 24 s. The ISS (1922) gave an origin time of the shaking at 11 h 47 h 24 s and an epicentre location at (36.5°N, 1.5°E). We note that neither the BCSS nor the ISS had assigned a magnitude to this earthquake. Ambraseys (1981a) has given an epicentre location at (36.39°N, 1.21°E) and assigned a magnitude at M_S = 5.1. Rothé (1950) had given a different location of the epicentre at (36.283°N, 1.267°E) and a magnitude M = 5.1. Karnik (1969) has also assigned an epicentre location at (36.3°N, 1.3°E) and a magnitude m_b = 5.0. Mezcua and Martinez (1983) have given an epicentre at 36.41°N, 1.20°E and a magnitude at m_b = 5.1. We have remarked that Gutenberg-Richter did not include this earthquake into their general list of epicentres.

3. Casualty and damage distribution

An important search of historical documents related to this earthquake was made in libraries and archive centres. The data collected from different sources has been used in the re-evaluation of the earthquake characteristics. The data available for this earthquake describe quite well the damage in the affected zone. All the sources give evidence on the complete destruction of the village of Cavaignac.

In Cavaignac the earthquake caused a veritable disaster as reported by the scientific documents and the local press. A violent shaking was felt at approximately 11 h 50 min in the Orléansville-Tenes region and particularly at the village of Cavaignac where most of the houses were down or severely cracked. Over 50 houses existing at that time, 40 were completely destroyed and none of the rest was suitable for housing. The house of the deputy-mayor in the village was still standing with its facades riddled of cracks, some parts of the house were on the ground but the interior was horribly devastated: partition walls, doors, windows, ceiling and roof were jumbled with all the pieces of furniture. Across the road, just one wall was left from the bakery, the other parts were hardly recognizable showing the violence of the shock. Few houses were consolidated with steel reinforcement before the earthquake had resisted better, as far as the facades were concerned, but the devastation of the interior was terrible. The chapel and the city hall had experienced severe damage. The buildings of the gendarmerie which was newly built did not resist the shaking, the facades and all the buildings were seriously damaged. In the main street of Cavaignac, on a facade which was still standing by miracle, a placard saying «Hotel de Cavaignac» had its interior badly ravaged: the plaster was completely on the beds or on the floor, debris of glass were scattered anywhere on the ground, the bottles were overthrown from the shelves and all the furniture was overturned. Photographs taken shortly after the earthquake by the European and local press reporters show the ruined streets of Cavaignac. The number of casualties was very low, 4 dead and few injured. The phenomenon started with an extended underground rumbling recalling the passage of a big truck or a train. The duration of the shaking was about 15 s. The vertical component of the shaking was so large that the people felt the soil under their feet was uplifted by more than one metre then weighed down, then again uplifted as it was animated by a sea wave movement. After this vertical shaking, most of the constructions were already down on the ground. Then horizontal oscillations started and the soil were moving as following a sea wave again. The thrust generated by the horizontal component caused the bending or the fall of the chimneys and the remaining houses. Low quality of construction contributed to the damage. Most of the constructions were in mud and stone masonry poorly or not at all reinforced, type A and B according to the MSK scale. Soil deformations were rare, a few cracks had been seen on the northern part of the village. In the east part of Cavaignac enormous blocs tumbled down from the sandstone corniche which was looking down upon Kalloul. The flows of the springs in the region were considerably higher up to five times than before the earthquake. Water was flowing in the ravines which were really dry before the shaking. The water level in the wells and Oueds had been raised up to 30 cm. The shock was violent causing the people of Cavaignac to flee their houses. People running in the streets and saying: «... this is the end of the world...»; as few weeks before the disaster, Dr. Milton A. Nobles of Philadelphia predicted the end of some parts of the world including Africa. People frightened by this prediction and feared another shaking, camped in the streets. In Talassa, located at about 32 km of Tenes and 14 km north of Cavaignac, according to the information available, the shock was strongly felt causing a partial destruction of the farm St. Louis and destroyed completely the houses of the Algerians around the farm. Most of the time, all the native Algerian houses around the settler's house were poor adobe, stone or mud and reed constructions. Here also, few people were injured mainly by the stones removed from the walls and falling roofs. In Kalloul, only 2 km from Cavaignac on the route of Tenes, the degree of shaking was less. Walls were severely cracked, roofs partially destroyed, furniture overturned, in over all, the damage was less that of Cavaignac. We have to say that Kalloul was much smaller in population and constructions than Cavaignac. Nine of the houses should be rebuilt completely. Few people were injured by the removed stones from the walls and by destructed roofs. In Mentenotte, northeast of Cavaignac, the shaking was also strongly felt causing heavy damage. Walls collapsed as most of the houses, the train station and the buildings of the city hall were severely cracked. Few people were injured. In Flatters, southeast of Cavaignac, the duration of the shaking was about 8 s. Most of the houses of the village collapsed or were seriously cracked but no casualties were declared. The population was all of a flutter during the earthquake. In Chasseriau, southeast of Cavaignac towards Orléansville, the village was also destroyed. The buildings of the gendarmerie experienced heavy damage and strongly cracked. The soil appeared this time to be very unstable. No casualties were declared. In Tenes, the earthquake had severely shaken most of the constructions. The whole city was all of a flutter during the 15 s of the shaking. The population had to flee in the streets fearing to see their houses collapse. The dogs fled in barking. The direction of the shaking was NE-SW. The «cite maritime» and its surroundings had suffered most. The ceilings, inner walls and chimneys suddenly collapsed. Fortunately there were damage on losses of properties but no serious casualties were reported. In Hanoteau, at a short distance to the east of flatters, at about noon when most of the people were having lunch, a strong extended rumbling was heard than immediately everything was shaking. Walls, doors, windows and tiles were strongly shaking. It was a violent 10 s shaking causing the people to flee their houses to the streets. The oscillations seemed coming from the west to the east. From the memory of an old Algerian, he said «... that was a unique shaking for its strength and the noise which preceded it...». There was losses of properties but no human casualty was reported. In Fromentin, southwest of Cavaignac, the shaking was in the NW-SE direction. It was strongly felt causing heavy damage to the properties but no human casualty was reported. The road Fromentin-Cavaignac was dislocated in several places (Vogt, 1993). In Cherchell, the shaking was strong enough to provoke a certain anxiety in the population; however the damage was not important. In Orléansville, south of Cavaignac, two shaking was felt with a duration about 5 s for each one. They occurred at one second time interval, the first one was in the direction west-east and relatively slow but the second was sudden and in the direction north-south. The clock of the city was stopped. Here also, the shaking was preceded by a strong rumbling. In Warnier, the shaking was felt but no damage was reported. In Relizane at about 100 km southeast of Cavaignac, the shaking was slightly felt by few people. In Alger at approximately 180 km northeast of Cavaignac, the shaking was also felt only by few people.

Analyzing all the damage data provided by the various sources available to us, intensities in the MSK scale were assigned sites where there is enough information. Maximum intensity has been assigned at I_0 = VIII-IX (MSK) to Cavaignac, VIII to Kalloul, Mentenotte, Chasseriau and Flatters, VII to Hanoteau and Fromentin, V to Cherchell, IV-V to Orléansville and Warnier, and III to Alger and Relizane. Additional search continues for the effects of the shaking in the villages in the east of Cavaignac between Cherchell and Alger and those in the west between Orléansville and Relizane which were not mentioned in any document.

From the intensity data an isoseismal map of the main shock has been drawn and is shown in fig. 1.

4. Magnitude determination

The surface-wave magnitude M_S of this earthquake has been calculated from the standard Prague formula (Vanek *et al.*, 1962), using 5 teleseismic amplitude and period readings from 5 stations located at distances between 1.5° and 18° and the macroseismic epicentre determined by this study at 36.42°N, 1.2°E. The data and the derived M_S value are shown in Benouar (1993). The mean period is about 8 s, the calculated value of M_S and the standard deviation, without station correction, are 5.1 ($\pm$ 0.3).

Also M_S is calculated using amplitude reading from an undamped Milne penduli at San Fernando (Spain) station. We have applied the calibration formula derived by Ambraseys and Melville (1982) for this type of instrument:

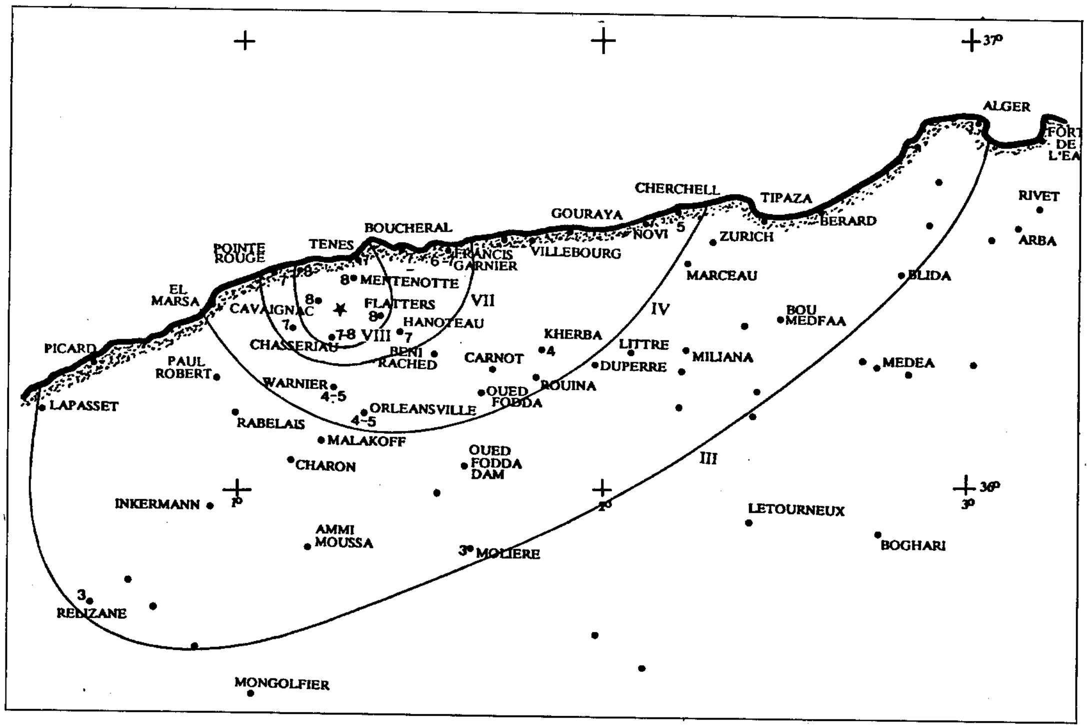

Fig. 1. Isoseismal map (in terms of MSK scale) of the main shock of the 25 August 1922 earthquake. The star shows the macroseismic epicentre.

$$M_S = \log(2A_t) + 1.25 \log(D) + 4.06 \quad (4.1)$$

Where $2A_t$ is the double amplitude in mm and D the distance in degrees, we have found that the equivalent M_S is 5.0. The data and results are shown in Benouar (1993).

5. Teleseismic relocation

The locations of all the Algerian and European seismological stations are practically on one side in respect to Algerian epicentres. They are all to the northeast which does not allow a precise instrumental determination of the epicentre. The precision of the epicentre location is increased by means of macroseismic study of the earthquake, and analysis of the difference generally observed between macroseismic and instrumental epicentres.

The readings were taken from original bulletins of 13 seismological stations. This earthquake was recorded at Alger-University (ALG) which is about 180 km away from the epicentre. Apart from Cartuja (CRT) and San Fernando (SFS) seismological stations in Spain which are slightly at the northwest of the epicentre, all the other stations are in the northeast quadrant in respect to the epicentre location. The solution from these reading depends evidently on the assumed trial origin. The final revised solution calculated from these readings with an assumed trial origin (36.5°N, 1.5°E) and using the present location procedure of the International Seismological Centre is:

1922 August 25
11 h 47 min 22 s (± 2.6)
36.4°N (± 0.24), 1.3°E (± 0.15)
Depth 0 km (SD 2.97).

Considering the accuracy of the timing systems at that time, comparing the instrumental epicentre (36.4°N, 1.3°E) to the macroseismic one (36.42°N, 1.2°E), we would say that the solution is consistent and acceptable. The instrumental epicentre is just shifted by 10 km towards the east, this is easily explained by the fact that most of the recording stations are east of Cavaignac. The east-west control is mainly assured by the readings from Cartuja and San Fernando (Spain).

6. Foreshocks and aftershocks

It apparently seems that the earthquake occurred without a foreshock. In the other hand, many aftershocks were felt in the region after the main shock but were not recorded by any seismological station. The main ones are: 27 August 1922 at about 10 h (Cavaignac); 28 August 1922 at 10 h 40 min (Cavaignac); 28 August 1922 at about 23 h (Taza, strong shaking) and the strongest is that of 29 August 1922 in the morning (Chasseriau, very strong shaking). This last and largest aftershock of the 25 August 1922 earthquake was preceded by an underground rumbling and was strongly felt in Tenes and Chasseriau. It caused the destruction of the forest house on the route of Orléansville (damaged by the main shock), few already cracked houses and bare walls in the Orléansville-Tenes region.

7. Discussion

Additional search of macroseismic information in different reports and in Algerian and European press had greatly improved our idea of the location of the epicentre, intensities reached and their degree of attenuation, depth and magnitude of this earthquake. From our results it appears that the earthquake was a shallow event. This is shown by: 1) the heavily destroyed area which exhibited intensity IX (MSK) was limited to the small village of Cavaignac and its close surroundings (of about 5 km radius); 2) the relatively small area over which the shock was felt. The intensity VIII (MSK) was reached over an area of radius about 20 km around Cavaignac, it caused sufficient damage to be recorded in contemporary documents. The intermediate regions of Orléansville (V) in the south, Relizane (III) in the west, Cherchell (V) and Alger (III) in the east were not described nor reported in any source.

In order to understand better the information contained in contemporary documents, one should take into account the socio-economic conditions, political and demographic situations, and the characteristics of the building stock prevailing at that time. Documents show that the colonial farms better built were sparsely distributed over the whole region and that the native Algerian were forced to leave their fertile land to remote areas in the mountains and valleys which made the report of macroseismic data scarce. It should also kept in mind that the French authorities rarely communicated information about the natives which considerably reduced the macroseismic information of this event. In similar situations, one should retrieve the information from government reports which, because of their official character, contain reliable data. Additional search for macroseismic information relative to this earthquake continues.

Summarizing the results of this research, we obtain the following data for the 25 August 1922 earthquake: origin time: 11 h 47 min 22 s; instrumental epicentre: 36.4°N, 1.3°E; macroseismic epicentre: Cavaignac 36.42°N, 1.2°E; focal depth: shallow of about 3 km; intensity: I_0 = IX (MSK); magnitude: M_S = 5.1 (± 0.3).

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The Mac-Mahon earthquake of 16 March 1924

Abstract
This research examines the largest seismic event felt and recorded in the oriental limits of the Saharan Atlas since the beginning of this century. On March 16, 1924, at 10 h 17 min 26 s (GMT), a destructive earthquake struck the southwest region of Batna. It centred in the zone contained between the Belezma Mounts, Djebel Metlili and the Aures Massif. The main shock, which lasted 8 s, caused the loss of 4 lives, injuring several and rendering numerous homeless; it destroyed or heavily damaged many local traditional houses (gourbis), colonial constructions and public buildings. The earthquake affected structures in the zone comprising Batna, Mac-Mahon, El Ksour, Arris and Victor Duruy. Most damage was observed in the city of Mac-Mahon and particularly in the douar El Ksour. The earthquake was strongly felt in the area enclosed between El Kantara, Bernelle, Barika and N'Gaous. The main shock occurred without a foreshock and was followed by three slight aftershocks. We found no evidence of any sign of ground deformations or liquefaction. Compilation and critical analysis of the contemporary sources relative to this earthquake has led to the reconstruction of its macroseismic data and thus the re-evaluation of the intensities. Maximum intensity has been re-estimated at I_0 = VIII (MSK), assigned to Mac-Mahon and douar El Ksour, and covers an area of about 8 km radius. The shock was recorded in many seismological stations up to Toronto and Victoria. The instrumental epicentre has been relocated, using the present ISC location procedure and readings from 20 seismological stations, at 35.4°N, 5.8°E. From the intensity data, an isoseismal map has been constructed and the macroseismic epicentre located slightly southwest of El Ksour at 35.427°N, 5.900°E. The surface-wave magnitude has been computed, without station corrections, at 5.35 (± 0.33).

1. Introduction

The region of Batna was shaken by a strong earthquake on Sunday, March 16, 1924, at 10 h 17 min 26 s (GMT). The main shock, which lasted 8 s, caused the loss of at least 4 lives, injuring several and rendering many homeless; it destroyed numerous local traditional houses (gourbis), colonial constructions and public buildings. The shock affected structures in the zone comprised between Mac-Mahon, Batna, Arris and Victor Duruy. Most damage was observed in Mac-Mahon and particularly in the douar El Ksour. The earthquake was seriously felt in El Kantara, Bernelle, Barika and N'Gaous. It seems that it occurred without a foreshock and followed by three slight aftershocks. We found no evidence of any sign of ground deformations or liquefaction.

In order to appreciate better the strength of the ground shaking, an extensive search was carried out in libraries and archives to collect contemporary documents relative to this earthquake. Compilation and critical analysis of the macroseismic information retrieved from these documents has led to a detailed appraisal of the amount of damage caused to man-made objects and to nature, and how it was felt by the population. As in past destructive earthquakes in Algeria and elsewhere, adobe, drystone and unreinforced masonry constructions experienced damage from heavy cracks to total collapse. The macroseismic data collected has allowed us to re-estimate intensities in various sites and to draw an isoseismal map of the main shock. Maximum intensity reached I_0 = VIII in the MSK scale, allocated to Mac-Mahon, douar El Ksour and their immediate vicinities, and covers an area of approximately 8 km radius. The main shock was recorded, in many seismological stations, up to Toronto and Victoria. The instrumental epicentre and focal depth were determined respectively, using the present ISC location procedure and readings from 20 seismological stations, at 35.4°N, 5.8°E and 3.7 km. From the intensity data, the macroseismic epicentre was located, slightly southwest of douar El Ksour, at 35.427°N, 5.900°E. Teleseismic amplitude and period readings from 6 stations with the standard Prague formula give a surface-wave magnitude, without station corrections, at 5.35 (± 0.33).

2. Sources of information

A comprehensive search for the contemporary sources relative to this earthquake has been made in order to reconstruct its macroseismic field with an appreciable degree of reliability. In spite of its significance, it is surprising to learn that the information on this event is rather scarce. The Algerian and French press, which used to describe destructive earthquakes with a great amount of details, failed to do so this time and limited their reports to colonial villages and towns. Many sparsely distributed douars, within the affected zone, which could have enriched the macroseismic data, were not mentioned. The most extensive newspaper account is given in «L'Echo d'Alger» (1924). However, there are very few reports of this earthquake that are known; these are limited to few line summaries of the effects of the event by Hée (1924) and Rothé (1950) who both used the press reports (1924). The macroseismic epicentre of the main shock was located at 35.5°N, 5.9°E by Rothé (1950) who is repeated by Karnik (1969) and Mezcua and Martinez (1983). The instrumental epicentre was calculated at 35.7°N, 5.8°E (Rothé, 1950); 34.5°N, 7°E (Strasbourg, 1924); 35.0°N, 6.0°E (ISS, 1924; Gutenberg and Richter, 1954). Magnitudes were determined at M_S = 5.60 (PAS); M_S = 5.5 (Karnik, 1969); M = 5.6 (Grandjean, 1954), M = 5.6 (Khemici, in EERI, 1983) and m_b = 5.6 (Mezcua and Martinez, 1983). Maximum intensity was assigned at IX (MS) (Karnik, 1969); VIII (MSK) (Mezcua and Martinez, 1983) and VIII (MM) (Khemici, in EERI, 1983).

3. Geographical aspects of the region

The earthquake occurred, in the oriental limits of the Saharan Atlas, at about 300 km southeast of the capital Alger. The epicentral area, which is centred in the zone containing the Belezma Mounts, Djebel Metlili and the Aures Massif, is located at about 30 km southwest of Batna. The region is characterized by a broken and high relief; the Belezma is culminating at 2178 m (Djebel Rafaa) and 2094 m (Pic des Cedres), Djebel Metlili at 1495 m and the Aures at 2326 m (Djebel Chelia) and 1865 m (Bouzina at about 20 km from the epicentre). The northern parts of these mountains preserve some beautiful afforestation, Alep pines, evergreen oaks or cedar trees. The cultivations are generally found in the valleys, they consist of fruit trees as apricot, almonds, fig and, in the small plains, which are sometimes met in the heart itself of the mountains, the cereals. The people of the region, which are known as Chaouias, live in fortified villages, perched at the crests of escarpments, which are sometimes accessible only by stairs or ropes. The typical native construction prevailing at that time, which constituted about 90 percent of the building stock exposed to the shock, consisted of mud-reed, mud-straw or stone bearing walls structures with, generally, a heavy roofs which make these dwellings highly vulnerable to earthquakes.

4. Damage and casualty distribution

Careful analysis of the macroseismic information, collected from a variety of contemporary sources available to us, has led to the re-evaluation of the amount of damage the earthquake had caused to man-made structures and to nature, and how the population behaved in several sites. Contemporary accounts revealed that, as in past destructive earthquakes in Algeria and elsewhere, adobe structures, which are characterized with high vulnerability and low strength, sustained significant damage from heavy cracks to total collapse. It was reported that the city of Mac-Mahon and particularly the douar El Ksour suffered most. The earthquake affected numerous structures in the zone between Batna, Arris, El Kantara, Victor Duruy, Barika and N'Gaous. The epicentral zone, within which the earthquake caused major damage, was not densely populated. Many douars sparsely distributed in various valleys and flanks of the surrounding mountains were not mentioned in any contemporary account.

The main shock, which lasted 8 s, killed at least 4 people, injuring several and making numerous homeless; it destroyed or heavily damaged many local traditional houses (gourbis), colonial structures and public buildings.

In Batna, it was 10 h 17 min (GMT) when a deafening underground rumbling was first heard which was followed immediately by a violent shaking. The oscillations were felt going from east to west direction. The shock was strong enough to make all the inhabitants, all in a flutter, flee from their homes to the streets, fearing other stronger shocks. Casualties were either not reported or not communicated. In the other hand, it was reported that the civil prison, the church and few constructions were badly damaged. At the negro village, in Batna, the mosque was partly destroyed and its minaret collapsed. In Mac-Mahon, a small village located at 32 km southwest of Batna, the shaking was particularly violent. The Bordj of the city was so seriously damaged that it had to be evacuated. No casualty were communicated. In El Ksour (city of Mac-Mahon), a douar situated at 8 km north of Mac-Mahon, the earthquake was strong enough to cause total destruction of the dwellings and loss of life. It is reported that numerous local traditional houses (gourbis) collapsed trapping under the rubble many people. Three children were reported killed and two injured (all natives). In Victor Duruy, a small village located at 20 km north of Mac-Mahon, the shaking was strongly felt. A wall of the stable of the settler Omont collapsed burying under its debris a young native girl who was killed. The house of Omont was so damaged that all the family had taken temporary refuge in the school. Propositions of relief and indemnities for the earthquake victims were made by the French administration. In Arris, a village located at 42 km east of Mac-Mahon, the shaking was violent enough to cause great panic among the population. No casualty were declared. It is reported that many houses suffered significant damage but no details were communicated. The press and all the writers (1924) mentioned that the shaking was seriously felt, with significant intensity, in El Kantara, Bernelle, Barika and N'Gaous but details were not given.

5. Intensity re-evaluation

Intensities were re-estimated, using all the macroseismic information inferred from a variety of sources, with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale. Critical analysis of the macroseismic data has revealed that many poor-quality houses, which constituted the building stock exposed to this

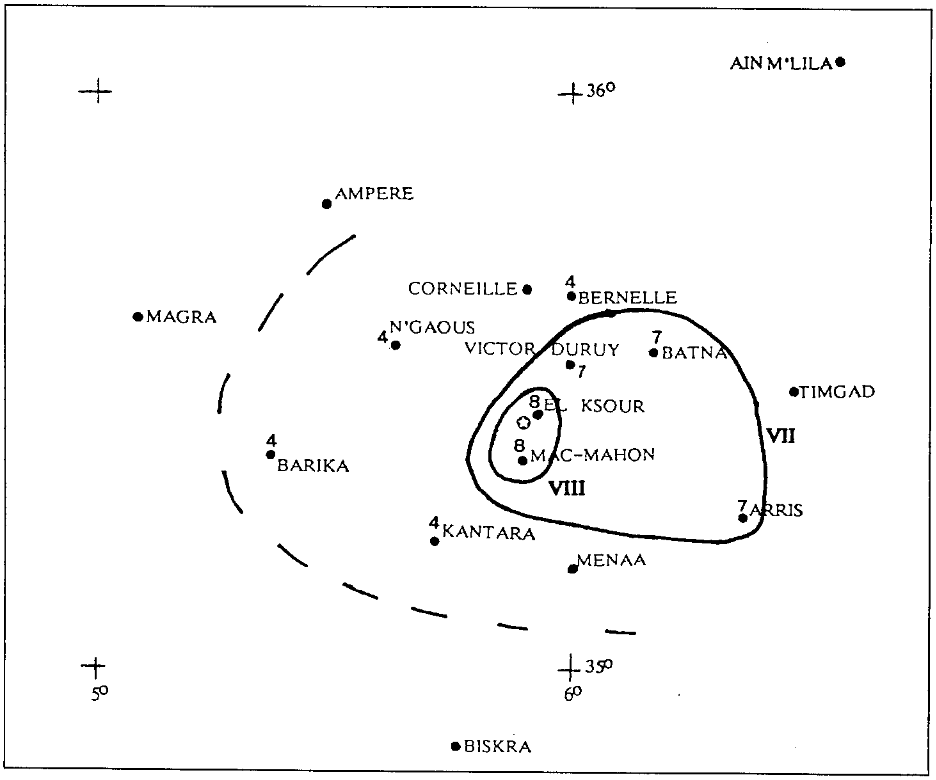

Fig. 1. Isoseismal map (in terms of MSK scale) of the main shock of the 16 March 1924 earthquake. The star shows the macroseismic epicentre of the main shock.

earthquake, were generally in an advanced state of decay, and suffered through ageing, negligence, rain, earthquakes and lack of proper repair.

After considerable study of the data collected, maximum intensity has been re-evaluated at I_0 = VIII (MSK), allocated to Mac-Mahon and its close vicinity, and centred in the douar El Ksour. Intensity VII was assigned to Batna, Victor Duruy and Arris. Intensity IV was attributed to El Kantara, Bernelle, Barika and N'Gaous. Intensities VII and VIII were allocated with a rigid interpretation of the MSK intensity scale (Medvedev *et al.*, 1981). Intensity IV was attributed on felt effect. From the intensity data, an isoseismal map of Mac-Mahon 16 March 1924 earthquake has been drawn and is shown in fig. 1 on which were plotted the intensity assigned to each site.

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 6 seismological stations located at distances between 2° and 26°, and a preliminary epicentre (macroseismic) at 35.427°N, 5.900°E. The data and the results are given in Benouar (1993). The mean period is 12.5 s and the derived value of M_S, without station corrections, is 5.35 (± 0.33).

7. Teleseismic relocation

The instrumental epicentre and the focal depth of this earthquake have been determined using the present location procedure of the International Seismological Centre (ISC) and readings from 20 seismological stations that reported the event to the International Seismological Summary (ISS). The main shock was recorded and reported by Alger-University, Helwan (Egypt) and by many European stations as far as Sverdlovsk 43° away. All the reporting stations were to the north of the epicentre, except that of Helwan, resulting in a poor azimuthal distribution of stations and epicentre. Stations with large residuals have been weighed small or out of analysis.

With a trial origin taken at 35.00°N, 6.00°E, we find:

1924 March 16
10 h 17 min 26 s (± 2.3)
35.4°N (± 0.22), 5.8°E (± 0.14)
Depth 3.7 km.

The details of the data and the results are given in Benouar (1993). This position agrees with the macroseismic epicentre with errors of about 3 km in latitude and 11 km in longitude.

8. Foreshocks and aftershocks

According to the contemporary sources available today, it seems that the earthquake occurred without any foreshock. In the other hand, it was followed by three slight aftershocks which occurred on March 17 at around 19 h and 21 h (GMT), and on March 18 at 1 h (GMT). These aftershocks were felt only in Mac-Mahon and its close surroundings but none of them was recorded by any station.

9. Discussion

In terms of the seismic history of the region reported by Chesneau (1892), Rothé (1950), Karnik (1969), Roussel (1973) and recently Mezcua and Martinez (1983) the Mac-Mahon earthquake occurred in a zone of the Saharan Atlas which experienced very few destructive earthquakes in the last two centuries. On 16 November 1869 which affected the Biskra region and on 17 January 1885 in the N'Gaous constitutes the main large earthquakes in the oriental limits of the Saharan Atlas. Thus, this event shows the potential for a higher degree of space and time inhomogeneities of the seismicity and the consequences of this in the estimation of seismic hazard in Algeria.

A detailed study of the 16 March 1924 Mac-Mahon earthquake is of great importance for various reasons. Firstly, it represents the strongest earthquake recorded in the Batna region. Secondly, it is one of the most destructive earthquakes which occurred in the region of the Aures massif during the last two centuries. Thirdly, the same epicentral area, which experienced destructive earthquakes in the past, displays today many of the human and geographical characteristics found in several other parts in Algeria. For these main reasons, a critical study of the effects of the earthquake, in this restricted zone, is pertinent to the whole northern part of the country, in terms of seismic hazard and risk evaluations. It provides a substantial means in minimizing future seismic disasters by suggesting new techniques in improving local building materials, construction methods, strengthening and properly repairing existing structures.

Analysis of the macroseismic information revealed that most native people dwellings were built of low-quality materials and were in a bad state. They were made of mud and straw, stone or adobe and were covered with a heavy thatched roof. This type of structure has shown, during past destructive earthquakes or even heavy rain, that its inherent strength is very low and variable and its vulnerability greatly high. Thus, as a result of the defectiveness of the majority of the building stock exposed to this shaking, the maximum intensity in any destructive earthquake in the region would seem the same. That is, at intensity IX (MSK), most the local traditional houses are destroyed and any settlement would look equally, but no more, devastated at higher intensities of the scale. For these reasons and after a careful analysis of the data retrieved, intensity IX was not clearly reached. Maximum intensity has been re-evaluated at I_0 = VIII (MSK), attributed to Mac-Mahon, El Ksour and their immediate surroundings, an area of approximately 8 km radius.

However, in order to study critically earthquakes of the past and better understand the information contained in the contemporary accounts, it is primordial to consider the political, socio-economic and demographic conditions, cultural and religious background and the characteristics of the building stock of the period concerned. According to the size of the ground shaking and the poor-quality structures, we believe that the damage and casualty rate, particularly among the native population, were certainly higher but details were not communicated by the French authorities for some reasons. Several sparsely distributed douars and isolated hamlets, within the affected zone, which could have enriched the data were not mentioned. It is certain that the exact number of casualty rate may never be known as many victims, buried immediately to conform the Islamic law, and their deaths were either not reported or simply left out by the French administration. It was thought that the information, as in other destructive earthquakes, would be ample, especially in the Algerian and French press. Unfortunately, this was not so; the information in all the contemporary documents available to us were scarce and limited to colonial villages and towns. The absence of information relative to the native population and their properties was manifestly guided by some kind of neglect exercised by the French administration. The matter of the limitation of information in native Algerian settlements is discussed in section 1. Chapter I. This may explain the reason why humans and property losses are very small for the size of the shaking and the type and state of the building stock of the region. In the colonial period in Algeria, ample and complete information can only be retrieved from contemporary military reports which, unfortunately, are not available to us today; because of their official character, this type of document contains more reliable data.

Summarizing the results, we obtain the following final data for the 16 March 1924 Mac-Mahon earthquake: origin time 10 h 17 min 26 s (GMT); instrumental epicentre 35.4°N, 5.8°E; instrumental focal depth h = 3.7 km; macroseismic epicentre 35.427°N, 5.900°E; maximum intensity I_0 = VIII (MSK); magnitude M_S = 5.35 ($\pm$ 0.33).

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The Ben Chabane earthquake of 5 November 1924

Abstract

This work presents one of the largest earthquakes that occurred in the Sahel of Alger. The Ben Chabane earthquake of 5 November 1924 occurred, without any foreshock, at 18 h 54 min 31 s (GMT); it is the strongest seismic event felt and recorded in the region since the beginning of the century. The main shock, which lasted 15 s, caused the loss of 2 lives, injured many more and rendered numerous people homeless; it destroyed or heavily damaged several housing units and colonial farms. The radius of perceptibility was relatively small, the shock being felt in Fort National 100 km away, with intensity III (MSK). The earthquake affected structures with intensity V^+ (MSK) in a zone about 2800 square km. Most damage was observed in the area containing Ben Chabane, Saint-Charles, Sainte-Amelie and their immediate vicinity. The main shock was recorded by many seismological stations in the world. The earthquake was followed by a long sequence of aftershocks with one strong enough to cause additional damage in the affected zone. Detailed study of the contemporary documents relative to this event has led to reconstruction of the macroseismic field and re-evaluation of the strength of the ground shaking. Intensities have been re-estimated in 53 sites and an isoseismal map has been constructed. Maximum intensity has been re-assessed at I_0 = VIII (MSK), allocated to Ben Chabane, Saint-Charles and Sainte-Amelie, an area of about 6 km radius. We found no evidence of any sign of ground deformations or liquefaction. The instrumental epicentre has been relocated, using the present ISC location procedure and readings from 11 seismological stations, at 36.6°N, 3.0°E. The macroseismic epicentre has been located slightly north of Ben Chabane at 36.64°N, 2.91°E. The surface-wave magnitude has been calculated, without station corrections, at 4.80 (± 0.08).

1. Introduction

On the 5th of November 1924 at 18 h 54 min 31 s (GMT) a destructive earthquake struck the Sahel of Alger. The epicentral zone, which centred in Ben Chabane, was located at 20 km southwest of the capital Alger. This earthquake occurred near where early destructive shocks had caused major damage (Rothé, 1950; Ambraseys and Vogt, 1988). The main shock, which lasted 15 s, caused the loss of 2 lives and rendered numerous people homeless; it destroyed many housing units and colonial farms and affected structures, with intensity V^+, within an area of about 2800 square km. The radius of perceptibility was relatively small, the shock being felt as far east as Fort National, south as Boghari and west as Cherchell, with intensity III^+ (MSK). The main shock was recorded by many seismological stations in the world which allowed us to relocate the instrumental epicentre, using the present ISC location procedure, at 36.6°N, 3.0°E. The earthquake occurred without any premonitory sign, but it was followed by a long sequence of aftershocks, continuing until early 1925. We believe that the casualty toll was relatively small because of the time of the occurrence, as many people were still outdoors and those who were indoors had fled their homes. The extent of damage observed was mainly due to the low-quality constructions that were common in the region at that time.

Collection and critical study of the macroseismic data retrieved from different contemporary sources relative to this earthquake has led to a detailed re-evaluation of the amount of damage caused to man-made structures and to nature, and how it was felt by the population. As in past earthquakes in Algeria, adobe, stone and unreinforced constructions suffered total destruction or heavy damage. The macroseismic information collected has allowed us to re-estimate intensities in 53 sites. Maximum intensity has been re-evaluated at I_0 = VIII (MSK), allocated to Ben Chabane, Saint-Charles, Sainte-Amelie and their immediate vicinity, and covers an area of about 6 km radius. According to the intensity data, the macroseismic epicentre was located north of Ben Chabane, at 36.64°N, 2.91°E. The surface-wave magnitude was calculated, without station corrections, at 4.80 (± 0.08).

2. Sources of information

The earthquake which occurred in the Sahel of Alger on the 5th of November 1924 is one of the most significant events in Central Algeria, not only because of its size, but because of its occurrence in one of the most densely populated areas, and also because it occurred where many destructive

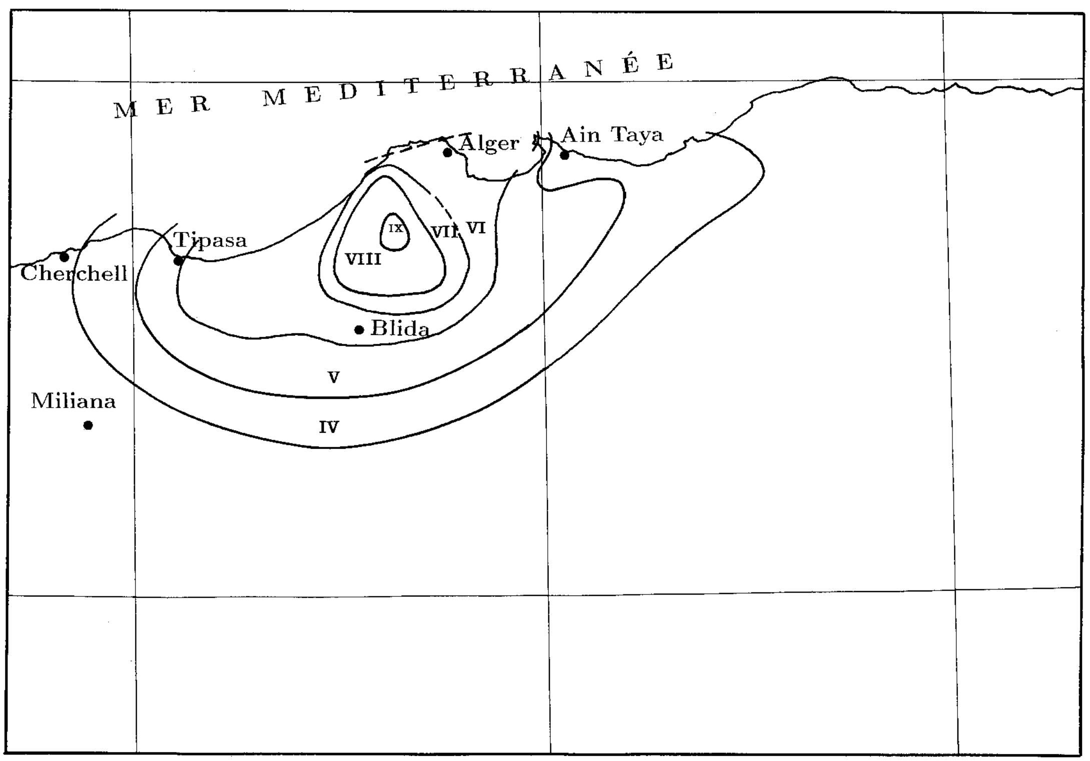

Fig. 1. Isoseismal map (MM scale) of the main shock of Ben Chabane 5 November 1924 earthquake, after Hée (1924). *Redrawn.*

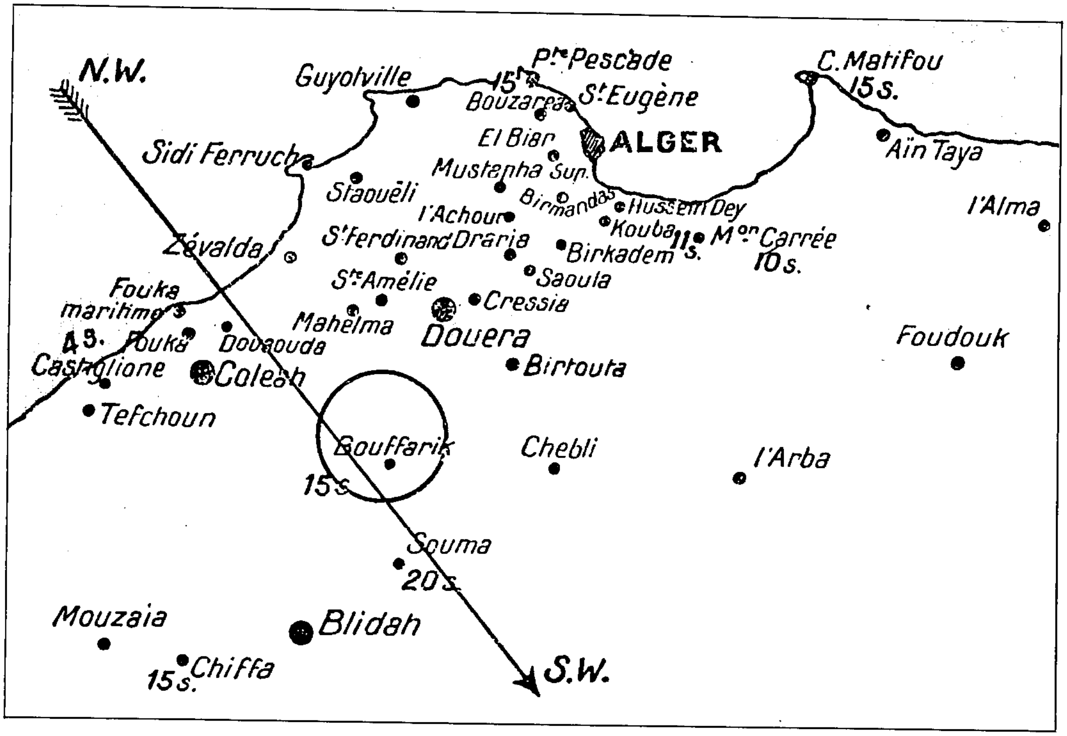

Fig. 2. Villages and towns affected during the Ben Chabane 5 November 1924 earthquake. The circle indicates the epicentre zone, after Murat (1925).

earthquakes had struck in the past. Because the epicentral region was one of the most important colonization zones, due to its fertile soil, water resources and climate, the earthquake was largely reported in the Algerian and French press and studied in detail by Hée (1924). The main sources used by Hée (1924) in describing the macroseismic data were direct reports from teachers in the affected region and the press. She, in a special note, described in detail the effects of the earthquake on human, man-made objects and on the ground itself. She assigned intensities in many sites and published an isoseismal map (fig. 1). She evaluated maximum intensity at I_0 = IX in the intensity international scale and allocated it to Ben Chabane, a small area of about 3 km radius. Murat (1925), without quoting his sources, summarized briefly the effects of the earthquake and published a map showing the affected villages and towns in the region (fig. 2). Cornetz (1925), a librarian of the city of Alger, described how he «predicted» the earthquake. Rothé (1950), repeating Hée (1925), summarized in a few lines the effects of the earthquake and located the macroseismic epicentre at 36.6°N, 2.9°E which was repeated by Karnik (1969). This event was also widely reported by the press (1924) because the damage was mainly to the French settlers farms. The most comprehensive account is given in «L'Echo D'Alger» which contains detailed macroseismic information. In the recent catalogues, the instrumental epicentre assigned to this shock is: ISS (1934), 35.3°N, 3.5°E which was reported by

Karnik (1969); Gutenberg and Richter (1954), 36°N, 4°E; Mezcua and Martinez (1983), referring to SSIS, 36.65°N, 2.9°E. Maximum intensity is evaluated at IX (Internationale scale), Hée (1924); VIII (MM), Khemici (1981); IX (MS), Karnik (1969) and IX (MSK), Mezcua and Martinez (1983). Magnitude is calculated at 4.90 (Rothé, 1950), M_S = 4.9 (Karnik, 1969), M_S = 5.60 (PAS), 5.00 (Khemici, 1981) and m_b = 5.2 (Mezcua and Martinez, 1983).

3. Geographical aspects of the region

The epicentral region of the Ben Chabane 5 November 1924 earthquake, which lies in the Mitidja plain, is at about 25 km southwest of the capital Alger. The Mitidja plain, which forms an inclined plane towards the sea with a slope of less than one percent, is contained between the Mediterranean sea and the Blidean Atlas which is an integral part of the Tell Atlas. Its altitude is about 25 m in the north and in the east, rises imperceptibly towards the Atlas, and is around 50 m in Boufarik, 140 in Beni Mered and 250 in Blida. The whole plain is well known for its fertile soil and water resources, which attracted numerous French farmers and thus native labour. With its splendid vineyards, orangeries and perfume plants, it constitutes a district of extraordinary wealth. Ben Chabane is a relatively small douar, north of Boufarik, inhabited by the people working in the surrounding colonial farms and orchards. As in all douars in Algeria, the buildings consisted of local traditional dwellings (gourbis) built mainly of mud-reed, mud-straw or drystone bearing walls with heavy roofs, which renders this type of structure highly vulnerable to earthquake forces. It is reported that more than 90 percent of the native population were living in rural settlements in gourbis during that time (Armature Urbaine 1987, 1988). Boufarik, which is between Alger and Blida, constitutes an important agricultural and livestock trade centre. Except the old part of the city, which is built of adobe bearing walls, most of the colonial houses were of drystone or ordinary brick masonry with clay or cement mortar joints.

The Mitidja plain constitutes one of the most important colonization zones; because of its location, close to the capital, its agricultural vocation and climate, it was the most densely populated area in Algeria.

4. Damage and casualty distributions

The Ben Chabane earthquake of 5 November 1924 occurred, without any foreshock, at 18 h 54 min 31 s (GMT); it centered about 20 km southwest of the capital Alger. Macroseismic data collected from different contemporary sources revealed that, as in past earthquakes in Algeria, adobe, stone and unreinforced masonry buildings suffered most damage. Most of the damage was observed in the localities of Saint-Charles, Ben Chabane, Sainte-Amelie and their immediate vicinity.

In Ben Chabane, a small village located at 20 km southwest of Alger, the shock was strong enough to make people flee their houses in a panic. Three local traditional houses (gourbis) were reported razed to the ground. The surrounding farms also sustained major damage. In the farm Marabout, the exterior walls were seriously cracked and the interior of the buildings were in ruins, wich was a jumble of glass, bricks and furniture. In the farm Descombes, damage to buildings consisted of the destruction of an old stone and clay hangar as well as the overthrow of chimneys and the collapse of their stacks, which damaged the roofs. In a native Algerian farm, an old construction (built during the Turkish period) of which the thickeness of the walls was between 80 cm to 100 cm major damage such as deep cracks in the facades and collapse of inner walls and stairs was sustained. In an another farm, recently built, a stable was completely destroyed. Many other surrounding native farms, which were not mentioned by name, suffered significant damage and threatened of collapse. We found no estimate of the number injured and homeless in this locality. In the route between Ben Chabane and Sainte-Amelie, a small farm belonging to Catala was seriously cracked, as well as the farm Treuil, where the clock fell to the ground and the contents of a sideboard were jumbled by the shaking. In Sainte-Amelie (city of Douera), a group of colonial farm situated at 5 km north of Ben Chabane, the shaking was so strong that all the population fled their outdoors, fearing the collapse of the buildings. In the farm Tourne, the stable totally collapsed, burying the livestock. Damage to buildings of the farm was very severe. The villa was completely destroyed, particularly in its upper part, which was in ruins. In the farm Remy, a hangar collapsed crushing agricultural equipment and, in the house, books were thrown from shelves to the floor. The local school was fissured in all its facades. In Saint-Charles, a large colonial farm located at 5 km northeast of Ben Chabane, the shock was strongly felt by the population. South of the locality, a three storey building, accommodating eight families, was significantly damaged, all the gables being destroyed, the chimneys overthrown and the walls loosened at the four corners. Many of the recently built constructions suffered such major damage as large cracks in walls. Vats containing hundreds of hectolitres of wine, built in masonry, were seriously fissured and threatening collapse. The farm of the Guardiola, built on a small hillock, was completely destroyed; the father had his arm broken by falling stones and his 17 year old son died of head injuries. In Boufarik, 6 km south of Ben Chabane, the shaking, which lasted about 15 s, caused major fissures in the exterior and partition walls, falls of plaster, loosening of walls and the fall of chimneys. Few poorly built houses were completely destroyed. The steeple of the church was set over. Many people camped for more than a week in the streets and in the open field. The rumbling produced by the shaking was like a strong thunder. The oscillations occurred first in the SW-NE direction and then from bottom to top. In Douera, a small village located at 8 km northeast of Ben Chabane, the shaking caused considerable concern and alarm among the population. Strong underground rumbling increased during the shaking. The main shock, which lasted 15 s, caused serious damage which consisted of fall of about ten chimneys, large and deep fissures in walls and inner walls loosened. It caused the displacement by 4 to 6 cm of heavy objects and, particularly, a marble toilet slab weighing between 50 to 60 kg. The town hospital sustained severe damage and the patients, particularly the children, were seriously frightened. In Mahelma, 7 km north of Ben Chabane, the shaking was so strong that the population had to flee their homes. The oscillations were in the N-S direction and the earthquake was preceded by a deafening underground rumbling. Damage to buildings consisted of serious fissures, collapse of walls in the surrounding farms and cracks in wine vats as in Saint-Charles (Vogt, 1993). A substantial decrease of the flow of the springs was observed. In Oued El Alleug, 10 km southwest of Ben Chabane, the shaking was strong enough to cause alarm among the population and serious damage in structures. The population fled their homes and camped in tents for almost a week. The earthquake was preceded by an underground rumbling and the oscillations were in the SW-NE direction. The shaking, which lasted 15 s, caused the fall of two chimneys, removal of tiles and cracks in the newly built houses. The electric current was interrupted during the shaking. The farm Mariano, in the close vicinity of Mahelma, at the site called Ben Koula on the road between Oued El Alleug and Boufarik, was significantly damaged and more than 18 rooms were rendered uninhabitable. In Les Quatres Chemins, 6 km east of Ben Chabane, on the route of Saint-Charles, numerous houses were destroyed and many others seriously cracked. In many places walls totally collapsed. In the Videau property the facade of the house was in ruins and ceilings fell to the ground, but fortunately the inhabitants had fled to safety. In the farm manager's house, large fissures and severe damage to the walls occurred, rendering the house uninhabitable. Most of the furniture and dishes were broken. In the courtyard of the farm, the earthquake broke a water pipe and a large ground surface fissure developed. In Saint-Ferdinand, 11 km north of Ben Chabane, in the house of a man called Childs, 5 to 6 m of cornice were removed, chimneys were overthrown and walls seriously fissured. In the farm Paris, the walls of an inhabited building collapsed. In Staoueli, the shock was accompanied by a strong underground rumbling. The oscillations were felt in the NE-SW as well as in the vertical direction. Most of the damage consisted of deep cracks in the walls of several houses. In Zeralda, numerous houses were seriously fissured. In Chebli the shaking, which lasted 10 s, was accompanied by a strong underground rumbling. In Saoula the shaking, which lasted 10 s, was felt in the vertical direction from bottom to top. The shock, which was preceded by a strong underground rumbling, was strong enough to cause such damage as cracks in walls and the fall of plaster from ceilings. The church bell rang three times during the shaking. The earthquake caused considerable concern and alarm among the whole population and badly disturbed the poultry. In Baba Hassen the shaking, which lasted 10 s, was accompanied by a strong underground rumbling. The oscillations were in the NW-SE direction. In Bouinane, a small village located at 13 km southeast of Ben Chabane, the shaking, which lasted between 12 and 15 s, was strong enough to cause small cracks in the walls of old houses and dislodge scores of bricks. It was preceded by an underground rumbling. The oscillations were felt in the NW-SE direction. In Crescia the shaking was in the N-S direction and also in the vertical, from bottom to top. It was strong enough to cause cracks in ceilings and the fall of plaster. The shock was preceded by an underground rumbling. In Alger, 25 km northeast of Ben Chabane, the shock was strong enough to cause total panic among the whole population, and particularly those who were in the theatres, though no appreciable damage was reported. At the quarters of La Marine and Bab El Oued, where the shaking was most strongly felt, people spent most of the night in the open, fearing stronger shocks. In Bouzareah the shaking was felt for a period of 15 to 20 s. The oscillations were reported in the SW-NE direction. A pendulum clock in the seismological station stopped. In Draria the shock caused a few cracks in walls and ceilings. It was preceded by an underground noise. In Souma the duration of the shaking was 12 s and caused great concern and alarm among the population. Underground rumbling similar to that caused by a light truck was reported in the area. The oscillations were felt in the N-S direction as well as in the vertical, from bottom to top. Many partition walls were loosened and fissured in the city hall buildings. In El Biar the shaking, which lasted 4 s, caused significant concern and alarm among the population. It was preceded by a strong underground shaking which was like that due to a violent hurricane. The oscillations were reported in the N-S direction. Damage consisted of expansion of existing cracks particularly in the boys' school and the fall of a small balance. Doors and windows were seriously shaken. The level of water in wells underwent a temporary drop of about 4 m. In El Achour the duration of the shaking was 15 s. The earthquake was strong enough to cause total panic among the population, but no damage was reported. In Hussein Dey the population felt the shaking for a period of 15 s. The earthquake stopped a pendulum clock and caused the fall of small objects fastened to walls. In Castiglione the shaking, which lasted 4 s, caused a few cracks in walls and ceilings as well as the displacement of furniture. In Kolea the earthquake was felt by the population during a period of 15 s. The shaking was reported to have felt like that due to a heavily loaded truck. Damage consisted of a few cracks in the old buildings of the village and its surroundings. In Douaouda the shaking was strongly felt by the population and accompanied by an underground rumbling. The oscillations were reported in the NW-SE direction. In Fouka the shaking was violent enough to frighten the inhabitants and cause them to flee their homes to the streets. In the «Cafe de la poste», a dreadful crush at the doors resulted in injuries to some of the customers. The main damage consisted of cracks in the ceilings of the town hall buildings. In Blida the earthquake was preceded by an underground rumbling. The oscillations were felt in the E-W direction. A smell of sulfurus gas was reported in the zone shortly after the main shock. In Beni Merad, at ground floor level, the shaking lasted 3 s. It caused considerable concern among the inhabitants but no significant damage was reported. Intense rumbling like the roaring of far away thunder was heard in the village and its vicinity. In La Chiffa the duration of the shaking was between 13 and 15 s. The oscillations were reported in the SW-NE direction. The main shock, which was accompanied by a deafening rumbling, was strong enough to frighten the population and make them flee their houses. In Sidi Moussa, the shaking was violent and the oscillations were felt in the W-E direction. Damage consisted of cracks in a few walls and ceilings. In Ameur El Ain the shaking lasted about 4 s and was preceded by an underground rumbling. Damage was confined to slight cracks in various buildings. In Bourkika, the shaking was violent enough to produce cracks in a few houses. In Birmandreis the shock was felt outdoors and preceded by an underground rumbling. In Cap Matifou the shaking, which lasted 12 to 15 s, was strong enough to frighten the inhabitants, and particularly those in the higher storeys. It was accompanied by a deafening rumbling, but did not cause any damage. In Birkadem the duration of the shaking was about 12 s. It was accompanied by an underground rumbling. The oscillations were in the W-E direction. In Maison Carrée, the shaking was felt by the population during a period of 15 s. It was reported that windowpanes and small glass objects were broken and furniture displaced. Most damage consisted of expansion of existing fissures. The water authorities of the city reported a substantial increase of the flow of the artesian wells. In Fort de l'Eau, the shaking lasted about 10 s and the oscillations were reported in the W-E direction. The earthquake was accompanied by a deafening underground rumbling but no damage was reported. In El Affroun the shaking, which lasted about 5 s, caused substantial concern but no great alarm among the inhabitants of the area and only insignificant damage such as very slight cracks. The impression of the shaking was of a heavily loaded truck. In Mouzaiaville the duration of the shaking was about 10 s. The oscillations, which were in the SW-NE direction, were felt as a slow swaying and an underground rumbling accompanied the earthquake. The main shock was strong enough to cause panic among the population but no significant damage was done to structures. In Arba the shaking, which was felt for 10 s, was accompanied by a rumbling similar to far away thunder. In Tipaza, the earthquake was strong enough to cause a few fissures in ceilings. In Alma the duration of the shaking was between 12 and 15 s, the population was frightened and a few fled their homes. No damage was reported. In Marceau the shaking lasted about 8 s and was accompanied by an underground shaking. No serious damage was declared. In Ain Taya the shaking was slightly felt by a few people. In Rouiba the shaking lasted 10 s but did not cause any damage or concern among the population. In Menerville the oscillations were felt in the N-S direction. The shock, which was accompanied by rumbling, caused great concern among the population. In Beni Amrane, Bordj Menaiel and Isserville the shaking was felt indoors by many people and outdoors by a few. The vibration was like that due to a heavy truck. In Cherchell, Boghari, Miliana and Fort National the shaking was slightly felt indoors by only few people.

5. Intensity re-evaluation

Intensities were re-estimated, using all the macroseismic information collected from different sources, with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale.

Critical analysis of the macroseismic data obtained has led to a detailed re-assessment of how much damage was caused to human and man-made objects and to nature. The building stock exposed to the shaking, which was characterized by adobe, stone and ordinary masonry constructions, suffered major damage. As stated by certain sources, many of the houses in the affected zone were in an advanced state of deterioration; they suffered through ageing, negligence, rain, earthquakes and lack of proper repair. Many of these dwellings had sustained heavy damage during destructive earthquakes that had struck the region in the past and so had been repaired more than once.

As a result of the dilapidation of these structures, maximum intensity in any destructive earthquakes in the villages and douars would appear to be similar. That is, at intensity IX on the MSK intensity scale, most of the dwellings would be totally destroyed and any settlement would thus look equally, but no more, devastated at higher intensities of the scale.

Detailed study of the reconstructed macroseismic field has led to the re-estimation of intensities at 53 different sites. Maximum intensity was re-evaluated at I_0 = VIII (MSK), attributed to Ben Chabane, Saint-Charles, Sainte-Amelie and to the immediate vicinity of these localities, an area of about 6 km radius. This intensity was assigned to the zone where maximum damage such as collapse of structures and loss of life were observed. Intensity VII was confined to Boufarik, Mahelma, Oued El Alleug, Les Quatres Chemins, Saint-Ferdinand and Staoueli. Intensity VI was attributed to Saoula, Baba Hassen, Bouinane, Crescia, Souma and Draria. Intensity V was allocated to Alger, Bouzareah, El Achour, Hussein Dey, Castiglione, Kolea, Douaouda, Fouka, Blida, Beni Merad, La Chiffa, Sidi Moussa, Ameur El Ain and Bourkika. Intensity IV was attributed to Birmandreis, Cap Matifou, Birkadem, Maison Carrée, Fort de l'Eau, Mouzaiaville, Arba, Tipaza, Alma and Marceau. Intensity III was confined to Ain Taya, Rouiba, Menerville, Beni Amrane, Bordj Menaiel, Isserville, Fort National, Boghari and Cherchell. Intensities V to VII were attributed with a rigid interpretation of the MSK intensity scale (Medvedev *et al.*, 1981). Intensities III to IV were allocated solely on felt effect and on the evidence of absence of damage to low-quality constructions. From the intensities thus re-evaluated, an isoseismal map of the Ben Chabane 5 November 1924 earthquake has been constructed and is shown in fig. 3, on which are plotted the intensity assigned to each site.

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 3 seismological stations located at distances between 12° and 18°, and a preliminary epicentre (macroseismic) at 36.64°N, 2.91°E. The data and the results are presented in Benouar (1993). The mean period is 11 s and the derived value of M_S, without station corrections, is 4.80 (± 0.08).

7. Teleseismic relocation

The instrumental epicentre of the earthquake was relocated using the present loca-

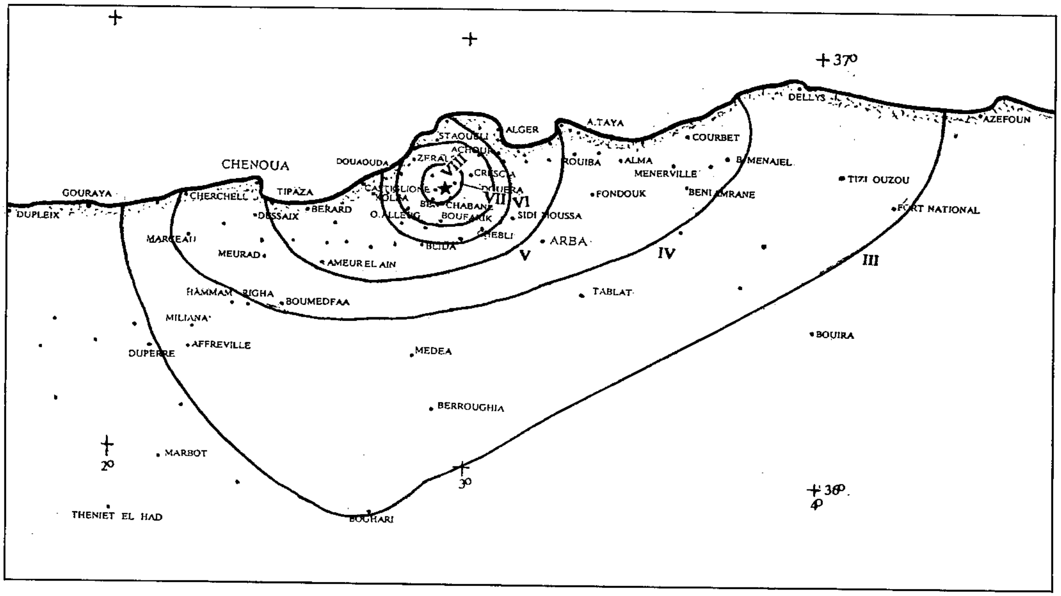

Fig. 3. Isoseismal map (MSK scale) of the main shock of Ben Chabane 5 November 1924 earthquake. The star shows the macroseismic epicentre of the main shock.

tion procedure of the International Seismological Centre (ISC) and readings from 11 seismological stations that reported the event to the International Seismological Summary (ISS). The main shock was recorded in Alger-University station (ALG) and through Europe as far as Sverdlovsk 43° away. All the reporting stations were in Europe, so they were all to the north, resulting in a poor azimuthal distribution of stations and epicentre. Stations with large residuals have been weighed small or left out of the analysis.

With a trial origin taken at 35.3°N, 3.5°E, we find:

1924 November 5
18 h 54 min 31 s (± 2.9)
36.6°N (± 0.23), 3.0°E (± 0.22).

This position agrees with the macroseismic epicentre with errors of about 5 km in latitude and 10 km in longitude.

8. Foreshocks and aftershocks

We found no evidence that the main shock was preceded by any premonitory sign. On the other hand, it was followed by numerous aftershocks, continuing until early 1925. Ninety eight aftershocks were recorded in Alger up to the end of 1924 and others in the beginning of 1925. Among these aftershocks 25 were felt of which a few were of medium intensity (Hée, 1924).

The largest aftershock occurred on 6 November 1924 at around 5 h 15 min (GMT). It was strongly felt in the affected zone where it added some damage, and up to Alma 50 km away. In Saint-Charles this aftershock was strong enough to complete the destruction of a building in the farm Frogger which was seriously cracked during the main shock (VI MSK). In Souma it caused the fall of plaster from walls (V MSK). In Maison Carrée a pendulum clock stopped. In Fort de l'Eau the shock, which was accompanied by a deafening rumbling, caused cracking of doors and windows (IV MSK). In Arba the shaking was seriously felt (Vogt, 1993). In Maison Blanche the shock was slightly felt (Vogt, 1993). Of the largest aftershocks, that of 6 November 1924 at 23 h (GMT) caused some concern in the affected region.

It is also of interest to mention the aftershocks that occured during the night of 8 to 9 November 1924 at about 22 h and 1 h which produced some panic in Douera (Vogt, 1993).

9. Discussion

In terms of the seismic history of the region reported by Rothé (1950) and Ambraseys and Vogt (1988), the Ben Chabane 5 November 1924 earthquake is one of the most significant seismic events to occur in the Sahel of Alger. Thus, this earthquake is by no means unreported. This event shows the potential for a higher degree of inhomogeneity of the seismicity and the consequences of this in the establishment of seismic hazard in Northern Algeria.

The reconstruction of the macroseismic field of the 5 November 1924 earthquake is of great interest for many reasons. First, it represents one of the strongest felt and recorded seismic events in the region since the beginning of the century. Second, the same epicentral area, which had experienced many destructive earthquakes in the past, displays today many of the human and geographical characteristics met in other parts of Northern Algeria. For these reasons, a critical study of the impact of this event on human and man-made objects and on nature is pertinent to the whole northern part of the country, in terms of seismic hazard and risk evaluation. It contributes substantially to the reduction of future seismic catastrophes by recommending new techniques in improving local construction procedures, building materials, strengthening and proper repair of existing structures and layout and implementation of new urban and rural settlements.

During this earthquake, we noted the ease with which local traditional houses, and even the colonial unreinforced masonry constructions, were destroyed or heavily damaged. In fact, the dwellings of the native people were of very poor-quality materials and in a bad state; they were mainly built of mud and straw, drystone or simply adobe and were generally covered with a heavy thatched roof. Most of them were partly below street or courtyard levels, the soil inside having been used as material to build, enlarge or repair the house. The houses in the douars, in contrast with the colonial farms, which were sparsely distributed, were built very close together in clusters, separated by narrow alleys. The general conclusion that may be drawn about the typical native people housing units is, therefore, that its inherent strength is very low and greatly variable and its vulnerability extremely high. Thus, as a consequence of the fragility of the building stock exposed to the shaking, the maximum intensity in any destructive earthquake in the region would appear the same. That is, at intensity IX (MSK), all adobe, stone and ordinary masonry constructions would be destroyed and any site would look equally, but no more, devastated at higher intensities of the scale. For these reasons, and after a detailed study of the macroseismic information collected, maximum intensity has been re-estimated at I_0 = VIII (MSK) and allocated to Ben Chabane, Saint-Charles, Sainte-Amelie and to their close vicinity, an area of about 6 km radius. The shock was felt in a relatively small area, as far as Fort National and Boghari, with intensity III^+ (MSK), more than 100 km away.

However, for a critical appraisal of past earthquakes and better understanding of the data contained in the contemporary sources, we should keep in mind the political, socio-economic and demographic conditions, cultural and religious background and the building stock characteristics of the period concerned (Ambraseys *et al.*, 1983).

This earthquake seriously affected the Sahel of Alger, a narrow coastal band of less than 100 km wide west of the capital, Alger. The affected region, which is a portion of the Mitidja plain, was an important colonization farming zone which, by its fertile soil, important water resources and climate, attracted many French settlers as well as natives. According to the description of the damage, we believe that the casualty toll, particularly among the natives, was certainly higher, but details were not, for some reason, communicated by the French administration. Sieberg (1932), without quoting his source, reported a dozen deaths. Sparsely distributed douars in many intermediate sites within the radius of perceptibility, which could have enlarged the macroseismic data, were not mentioned. The information in the press was rather scarce and limited to colonial villages and towns. The lack of details about the native people affected was due to the negligence of the French administration rather than censorship which could have practised by the French army (see section 1. Chapter I). This may explain the reason why property and human losses appeared disproportionately small for an earthquake of this size and considering the poor-quality constructions involved. We believe that in similar political situations, in order to avoid underestimating the effects of the earthquake, more reliable macroseismic information can only be inferred from contemporary military sources which, unfortunately, are not available to us today.

Summarizing the results, we obtain the following final data for the 5 November 1924 earthquake: origin time 18 h 54 min 31 s (GMT); instrumental epicentre 36.6°N, 3.0°E; macroseismic 36.64°N, 2.91°E; focal depth 3 km; maximum intensity I_0 = VIII (MSK); magnitude M_S = 4.80 (± 0.08).

The Inkermann earthquake of 24 August 1928

Abstract
This report considers the earthquake which occurred on 24 August 1928 in the Cheliff Valley to the west of the capital, Alger. On the 24th of August 1928, at 9 h 44 min 20 s (GMT), an earthquake caused major damage and loss of life in the city of Inkermann and its region in the Cheliff Valley. A broad investigation for contemporary documentary materials was carried out and the macroseismic information retrieved used for a detailed study of the impact of this event. As a result of this, intensities at many sites have been re-assessed, the macroseismic epicentre located, between Inkermann and Sainte Aimé, at 35.94°N, 0.88°E and an isoseismal map has been drawn. Maximum intensity has been re-estimated at I_0 = VIII (MSK), attributed to Inkermann, Sainte Aimé, Hamadena and their close vicinities, and covers an area of about 9 km radius. Most damage consisted of cracks in the settlers' buildings and heavy damage or collapse of the old native dwellings. The total number of casualties was not high, 4 people (all natives) being reported killed. The shock was felt as far as Boghari 200 km away. We found no evidence concerning any sign of ground deformations or liquefaction. The earthquake had produced new spouting springs on the right bank of the River Cheliff, of which many were petroliferous. The main shock was recorded, in many seismological stations, up to Georgetown (61°) and Irkoutsk (71°). The instrumental epicentre has been relocated, using the present location ISC procedure and readings from 42 seismological stations, at 35.9°N, 0.9°E. The surface-wave magnitude has been computed, without station corrections, at 5.40 (± 0.22).

1. Introduction

On Friday 24th of August 1928, at 9 h 44 min 20 s (GMT), a destructive earthquake struck the Inkermann region in the Cheliff Valley. The epicentral zone, which is centred between Inkermann and Sainte Aimé, lies within the Cheliff Valley, located at about 170 km west of the capital, Alger. The main shock caused the loss of at least four lives, injured many and made several people homeless; it destroyed or heavily damaged old native dwellings and cracked walls in the relatively well built settlers' buildings. The earthquake caused major concern among the population and produced slight damage, with intensity V^+ (MSK) in the zone encompassing Relizane, Montgolfier, Orléansville and their surroundings. We found no evidence concerning ground deformations or liquefaction. The most impressive phenomenon left behind by the earthquake was the spouting of several new springs, in the right bank of the River Cheliff, of which many were petroliferous. The radius of perceptibility was fairly large, the shock being felt as far as Boghari 200 km away. The main shock was preceded, two minutes earlier, by a foreshock and was followed by three slight aftershocks. The earthquake was recorded by many seismological stations up to Georgetown 61° and Irkoutsk 71° away. The instrumental epicentre has been relocated, using the present ISC location procedure, at 35.9°N, 0.9°E. Teleseismic amplitude and period readings from 13 seismological stations with the standard Prague formula give a surface-wave magnitude, without station corrections, at 5.40 (± 0.22).

Detailed study of contemporary documentary source materials relative to this event has led to a comprehensive re-assessment of the amount of damage caused to man-made structures and to the ground itself, and how it was felt by the population. It also revealed the type of buildings that existed at that time and the state they were in. We learned that, as in past destructive earthquakes in Algeria and elsewhere, most damage, which consisted of heavy damage or total destruction, was sustained by adobe and stone wall bearing structures. Careful analysis of the macroseismic data has enabled us to re-evaluate intensities in many sites. Maximum intensity has been re-estimated at I_0 = VIII (MSK), allocated to Inkermann, Sainte Aimé and the immediate vicinity of these villages, an area of about 9 km radius. From the intensity data, an isoseismal map of the earthquake has been constructed and the macroseismic epicentre located, between Inkermann and Sainte Aimé, at 35.94°N, 0.88°E.

2. Sources of information

For the reconstruction of the macroseismic field of the 24 August 1928 Inkermann earthquake, an extensive investigation for documentary source materials relative to this event was made in different libraries and archive centres. The result of this search is a collection of Algerian and French newspaper reports, and brief description summaries of the damage by Hée (1933) and Rothé (1950). Despite the loss of lives and extent of damage, we found no detailed study of the effects of the earthquake. We thought that the information would be ample, particularly, in the press, as for past destructive events. Unfortunately, this was not so; the information either in the press or in the brief reports in the descriptive catalogues is rather scarce and limited to colonial villages. In the press, the most comprehensive accounts are given in «La Presse Libre» and «La Dépêche Algérienne» (1928). No isoseismal map of this earthquake has been published.

In the recent catalogues, the instrumental epicentre was located at: 36.0°N, 0.00°E (Gutenberg and Richter, 1965); 34.3°N, 1.3°E (ISS, 1928) which is repeated by Karnik (1969); 35.966°N, 0.916°E (Mezcua and Martinez, 1983). The macroseismic epicentre was assigned at: 35.9°N, 0.6°E (Rothé, 1950) which is repeated by Karnik (1969). Maximum intensity was estimated at: VIII (MS), (Hée, 1933 and Karnik, 1969); VIII-IX (MS), (BCSA, 1928); VIII (MM), (Ambraseys *et al.*, 1983); VIII (MM), (Khemici in EERI, 1983) and VIII (MSK), (Mezcua and Martinez, 1983). Magnitudes were also calculated at: M = 5.4 (Grandjean (1957) in Karnik, 1969); M = 5.5 (Rothé, 1960); m = 6.3 (Munuera, 1963); M_S = 5.5 (Karnik, 1969 and Ambraseys *et al.*, 1983); M = 5.4 (Khemici in EERI, 1983) and m_b = 5.4 (Mezcua and Martinez, 1983). Gutenberg and Richter (1965) classified this earthquake in class $M = d$.

3. Geographical aspects of the region

The Cheliff Valley, which lies within the Tell Atlas to the west of the capital Alger, is near the northern limit of the African continental plate. The valley stretches east-north-eastward for about 200 km. The same epicentral zone, which is located at about 170 km west of Alger, has experienced many damaging earthquakes this century and particularly those of 9 September 1954 (M_S = 6.70) and 10 October 1980 (M_S = 7.40). Inkermann and Sainte Aimé, which suffered most, were two colonial farming villages built within the Cheliff Plain. In early colonization times, the French settlers had chosen the best sites in the Cheliff Valley, in terms of soil fertility, topography, water resources and communications. If the relatively well built colonization settlements were implanted on the lowest gentle slopes or in the plain, the native Algerian dwellings, grouped in douars, were poorly constructed and scattered in the high plateaux or sometimes dangerously on the abrupt slopes of the valleys, generally, near small springs which they used for their everyday needs and irrigation of the vegetable gardens. Apart from official buildings and some settler houses, all the native dwellings were of mud-reed, mud-straw or mud-stone bearing wall structures covered with heavy roofs, which made them highly vulnerable to earthquakes.

4. Damage and casualty distribution

To re-assess the extent of damage and the behaviour of the people with an appreciable degree of reliability, a comprehensive search for contemporary accounts relative to this event was made. The result of the analysis of the macroseismic data retrieved is a relatively good description of the impact of the earthquake on humans, man-made objects and on the ground itself. Maximum damage was experienced in a rather small area containing Inkermann and Sainte Aimé. The main shock caused the loss of at least four lives of native Algerians; details about injuries among the population and homeless people were not officially communicated.

In Inkermann, a small colonial village located at about 45 km southwest of Orléansville, the main shock, which was accompanied with an underground rumbling, caused loss of life and major damage. Most damage consisted of cracks in the relatively well built colonial constructions and heavy damage or total destruction of the local traditional houses (gourbis). It was reported that two native children were killed by the collapse of a wall and two old ladies were found dead under the rubble of their dwelling. The most impressive phenomenon left behind by the earthquake, in the Cheliff Valley on the right bank of the River Cheliff, was the spouting of several springs, of which many were petroliferous. Further west, at about 10 km of Inkermann, at Saint Aimé, the shaking was strong enough to cause great panic among the population and caused severe damage in the area. In the farms Gazelles, large newly built buildings, which had cost 400000 French Francs, collapsed totally, but no details were given. In Hamadena, a small douar situated 15 km west of Inkermann, the shaking was felt as strongly as in Sainte Aimé and caused significant damage, but details were not available. In Relizane, a relatively large village located at about 40 km west of Inkermann, the main shock, which lasted 13 s, caused slight damage to shops and houses. It was strong enough to cause considerable concern, but no alarm, among the population. The oscillations were in the east-west direction. The buildings, and notably the steeple of the church, were seriously shaken, but no major damage was reported. Forty five kilometres east of Inkermann, in Orléansville, the main shock, which lasted 4 s, was felt as strongly as in Relizane. It was strong enough to cause some slight damage, but no casualties. Damage consisted of a few broken objects in many houses in the region. In Montgolfier, a small colonial village situated at 50 km south of Inkermann, the main shock, which lasted 10 s, seriously shook the buildings and caused considerable concern among the population, but no details were given. In Perregaux, a colonial village located at 90 km west of Inkermann, the shaking was slightly felt and caused a certain concern but no alarm among the population. Many people did not feel the shock. Seventy kilometres northwest of Inkermann, in Mostaganem, the main shock, which lasted 10 s, caused no damage or casualty among the population. It was reported that the region suffered seriously from the 26 November 1927 flooding (L'Echo D'Alger, 1928). At 100 km east of Inkermann, in Duperré, the shaking was strongly felt but did not cause any damage or casualties among the population. Further east at about 180 km of Inkermann, in Blida, the main shock, which lasted 3 to 4 s, was accompanied by an underground rumbling. The shaking did not cause any damage or concern among the population. In Mascara, a village located at 20 km south of Perregaux, the shaking was slightly felt and caused little concern among the population. Seventy kilometres south of Inkermann, in Tiaret, the shaking caused some breaking of window panel glass (Vogt, 1993). The shaking was also felt in Frenda (Vogt, 1993). In Boghari, located at 160 km southeast of Inkermann, the shock was slightly perceived by the population.

5. Intensity re-evaluation

Intensities were re-estimated with reference to the Medvedev-Sponheuer-Karnik (MSK) intensity scale, using all the macroseismic information collected from contemporary sources. Analysis of the macroseismic field reconstructed has allowed us to re-evaluate intensities in many sites in the affected region. Maximum intensity has been re-estimated at I_0 = VIII (MSK), allocated to Inkermann, Sainte Aimé, Hamadena and the vicinity of these villages, and covers an area of 9 km radius. This intensity has been attributed to the zone associated with destruction of old local traditional houses and loss of life. Intensity V has been confined to Orléansville, Relizane and Montgolfier. This intensity has been assigned with rigid interpretation of the MSK intensity scale. Intensity III-IV has been allocated to Perregaux and Duperré. Intensity III has been confined to Blida, Boghari, Mostaganem, Tiaret and Mascara. These last intensities have been assigned solely on felt effects and lack of damage to poor-quality structures. From the intensity data, an isoseismal map of the 24 August 1928 Inkermann earthquake has been drawn and shown in fig. 1, on which are plotted the re-estimated intensities.

6. Magnitude determination

We have calculated the surface-wave magnitude of this earthquake from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 13 seismological stations located at 7° and 22°, and a preliminary epicentre (macroseismic) at 35.94°N, 0.88°E. The results are given in Benouar (1993). The mean period is 11.7 s and the derived value of M_S, without station corrections, is 5.40 (± 0.22).

7. Teleseismic relocation

The instrumental epicentre of the earthquake is calculated by using the present location procedure of the International Seismological Centre (ISC) and readings from 42 seismological stations that reported the event to the International Seismological Summary (ISS). The main shock was recorded in Alger-University, being the closest, throughout Europe as far as Irkutsk 70°, in the Middle East in Ksara (Lebanon) 29° and in the USA in Georgetown 61° away. Most of these reporting stations were in Europe, so were all to the north, resulting in a poor azimuthal distribution of stations around the epicentre. Stations with large residuals have been weighed small or left out of the analysis.

With a trial origin 34.3°N, 1.3°E and using the present location ISC procedure, we find:

1928 August 24
9 h 44 min 20 s (± 3.4)
35.9°N (± 0.34), 0.9°E (± 0.22).

This position agrees with the macroseismic epicentre with errors of about 4 km in latitude and 3 km in longitude.

8. Foreshocks and aftershocks

The main shock was preceded by a foreshock two minutes earlier and followed by

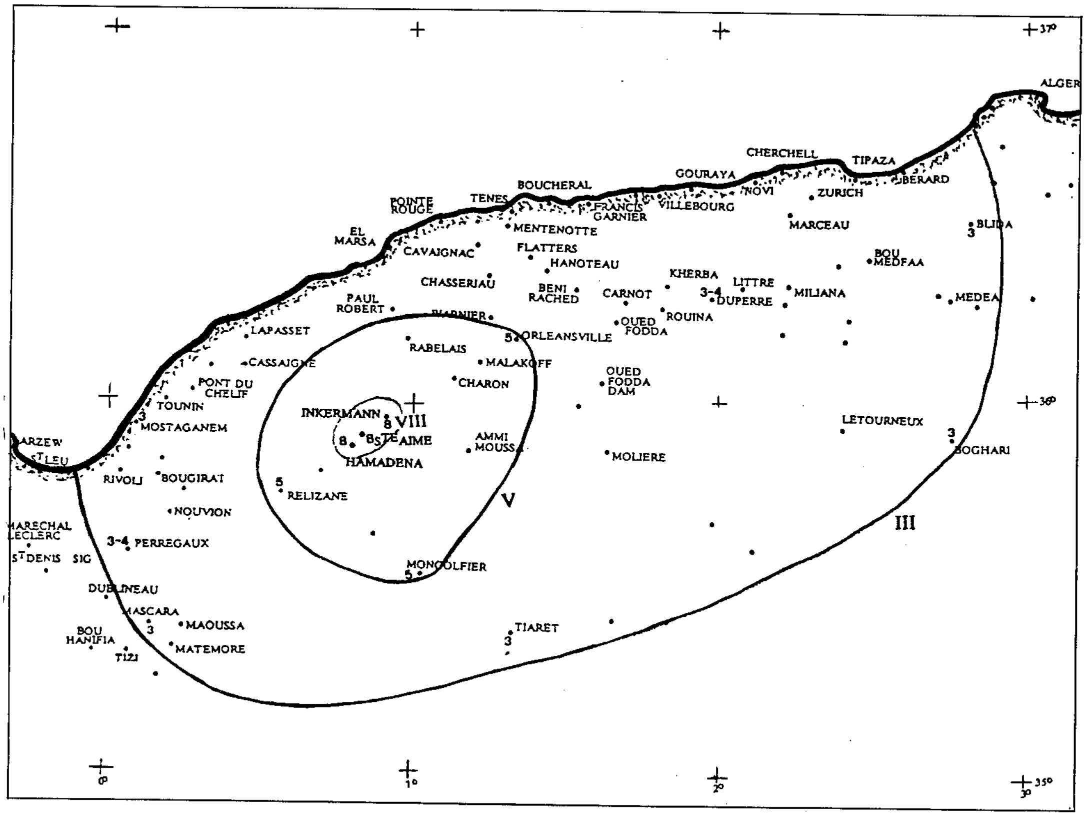

Fig. 1. Isoseismal map (MSK scale) of the main shock of the 24 August 1928 Inkermann earthquake. The star shows the macroseismic epicentre of the main shock.

three slight aftershocks the same day. The aftershocks were recorded at Alger-Bouzareah station. The first, which occurred at 10 h 28 min 48 s, was felt in Relizane. The last two, not felt by the population, occurred the same day at 12 h 18 min 40 s and 22 h 2 min 43 s (GMT).

9. Discussion

In terms of the seismic history of the region reported by Hée (1933, 1950), Rothé (1950), Benhallou and Roussel (1971), Mezcua and Martinez (1983) and Benhallou (1985), the Cheliff Valley has been the site of the region's largest known earthquakes, such as those of 9 September 1954 (M_S = 6.70) and 10 October 1980 (M_S = 7.40); thus, this event is by no means an exceptional one.

To re-assess the extent of damage and the behaviour of the population, a broad search for contemporary documentary materials relative to this earthquake was carried out in different libraries and archives. The information collected has revealed that poorly built constructions and their bad state were the main cause of damage. It has also shown that if the colonial buildings, relatively well built, sustained slight damage, the old local traditional dwellings (gourbis) experienced heavy damage or total collapse. Because the same epicentral area experienced destructive earthquakes in the past and exhibits today various human and geographical characteristics found in other parts of the country, a detailed study of the effects of this earthquake in this restricted zone is therefore pertinent to the whole of Northern Algeria, in terms of seismic hazard and risk evaluations. This will provide an important means to 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 implementation of new urban and rural sites.

However, to study earthquakes of the past critically and to appreciate better the information contained in the contemporary accounts, it is imperative that political, socio-economic and demographic conditions, cultural and religious background, and building stock characteristics be taken into account. The earthquake occurred in a period characterized by racial discrimination, misery, unemployment and poverty for the native Algerians. We noticed that the native people, who constituted more than 90 percent of the population in the region, were not mentioned in any contemporary document. Numerous douars, sparsely distributed in the plain and in the surrounding mountains, which could have enhanced the data, were not named. For this reason, we remain doubtful about the casualty toll and the extent of damage reported in the documents. We should keep in mind that, during that period, the French administration did not care much about the native population; this matter has been discussed in section 1. Chapter I. In similar situations, ample and more reliable information could be obtained from contemporary military sources.

Summarizing the results, we obtain the following final data for the Inkermann 24 August 1928 earthquake: origin time 9 h 44 min 20 s (GMT); instrumental epicentre 35.9°N, 0.9°E; focal depth 8 km; macroseismic epicentre 35.94°N, 0.88°E; maximum intensity I_0 = VIII (MSK); magnitude M_S = 5.40 (± 0.22).

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The Carnot earthquake of 7 September 1934

Abstract
This work presents the study of the earthquake that occurred in the Cheliff Valley on 7 September 1934. On Friday 7 September 1934, at 3 h 39 min (GMT), a destructive earthquake occurred in the Cheliff Valley which contains many types of adobe villages (douars) that are typical of many other parts of Algeria. The worst effects of the earthquake were observed in the small colonization village of Carnot and its surroundings. The duration of the main shock was about 15 s. The magnitude of the earthquake is re-calculated at M_S = 5.1 (± 0.2). The main shock was felt in the region comprised between Alger and Zemmora (225 km) and the coast and Tiaret (130 km). The epicentre of the earthquake, based on damage distribution, is estimated to be at the village of Carnot. The earthquake was preceded by few foreshocks and followed by many aftershocks which added further damage to the already weakened constructions. The epicentral region was already hard hit in the past, particularly by the Cavaignac earthquake of 25 August, 1922. Maximum intensity reached I_0 = VII in the MSK scale at Carnot, Saint-Cyprien, Les Attafs, Sainte-Monique and Wattignies. The earthquake caused no loss of life, but injured 11 people and destroyed several buildings. Although it is reported that considerable damage was caused and people in most villages camped under the tents, we found no report relative to the number of people made homeless or important relief operations. However, some sources have mentioned that the victims of the earthquake, without distinction of nationality, should receive legitimate indemnities to repair or reconstruct their properties. This earthquake, with a magnitude M_S of 5.1 is similar in size to the Cavaignac earthquake of 25 August 1922. Although they did not occur at the same site, their causes may be identical.

1. Introduction

In 1934, the seismic activity of Algeria had considerably increased, we counted more than 180 earthquakes. One of them is the 7 September 1934 which occurred at 3 h 39 min (GMT) in the Cheliff Valley and caused heavy damage to the village of Carnot and its surroundings. According to various reports on damage distribution, the macroseismic epicentre was very close to the centre of Carnot where most damage was observed. This colonization village was already affected by Cavaignac earthquake of 25 August 1922.

The shaking was widely felt, in Algeria, between Alger and Zemmora (about 225 km away) and the coast and Tiaret (130 km). The duration of the shaking was about 15 s. In the epicentral region, it was strongly felt and caused much damage at Carnot, Saint-Cyprien, Sainte-Monique, Les Attafs and Wattignies. The maximum intensity reached is re-evaluated at I_0 = VII (MSK). The magnitude of this earthquake is recalculated at M_S = 5.1 (± 0.2) from 9 seismograph stations.

The earthquake was preceded by few foreshocks and followed by a long sequence of aftershocks (more than one hundred between September and November). It apparently seems that this earthquake caused no loss of life, but injured 11 people and destroyed several buildings. There was no report on the number of people made homeless or organized relief operation, except the distribution of tents. In the Cheliff Valley as in many other parts of Algeria, except the official buildings and some settler houses made of reinforced concrete or good masonry, all the houses (gourbis) were made of adobe, clay and local stones or sun-dried mud bricks with a thatched roof, most of type A according to the MSK scale.

Similar phenomena present a great interest to the French colonization. The settlers had always accused the earthquakes, not only, of destroying their constructions but also of disordering the water flow, in the region, which may have positive or negative consequences.

2. Sources of information

A comprehensive search for documents relative to this earthquake was carried out in many libraries and archives. The macroseismic and instrumental data provided by the various types of sources contributed to the reconstruction of this event in all its aspects. Reports in the Algerian and international press are valuable, particularly re-

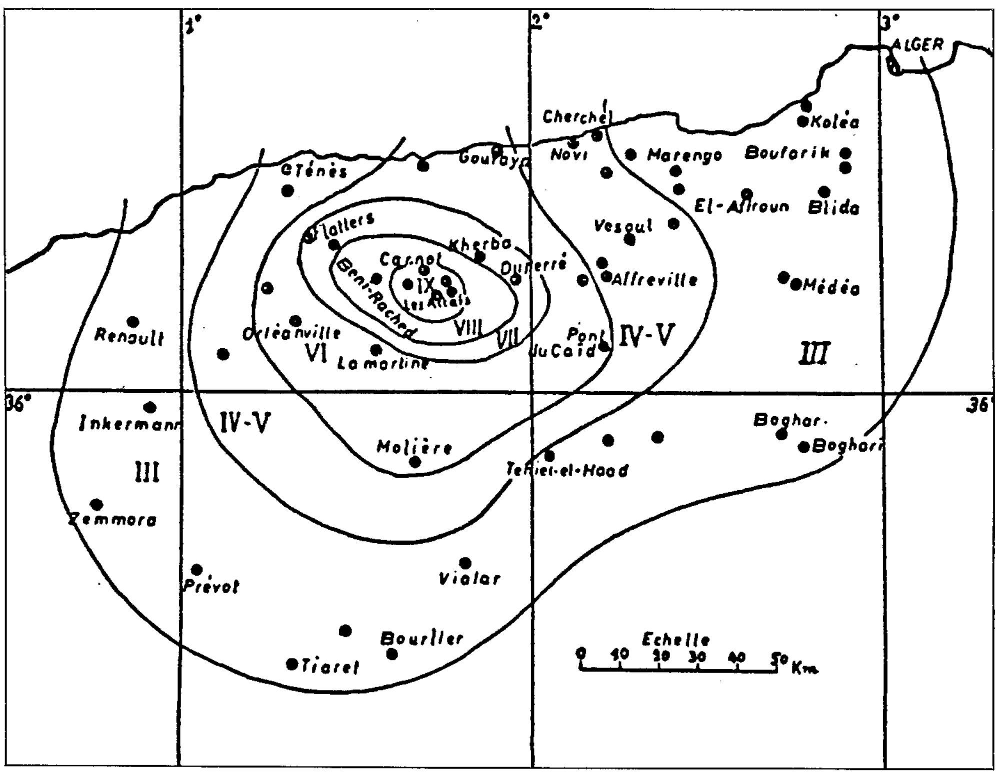

Fig. 1. Isoseismal map of the 7 September 1934 earthquake, after Hée (1936).

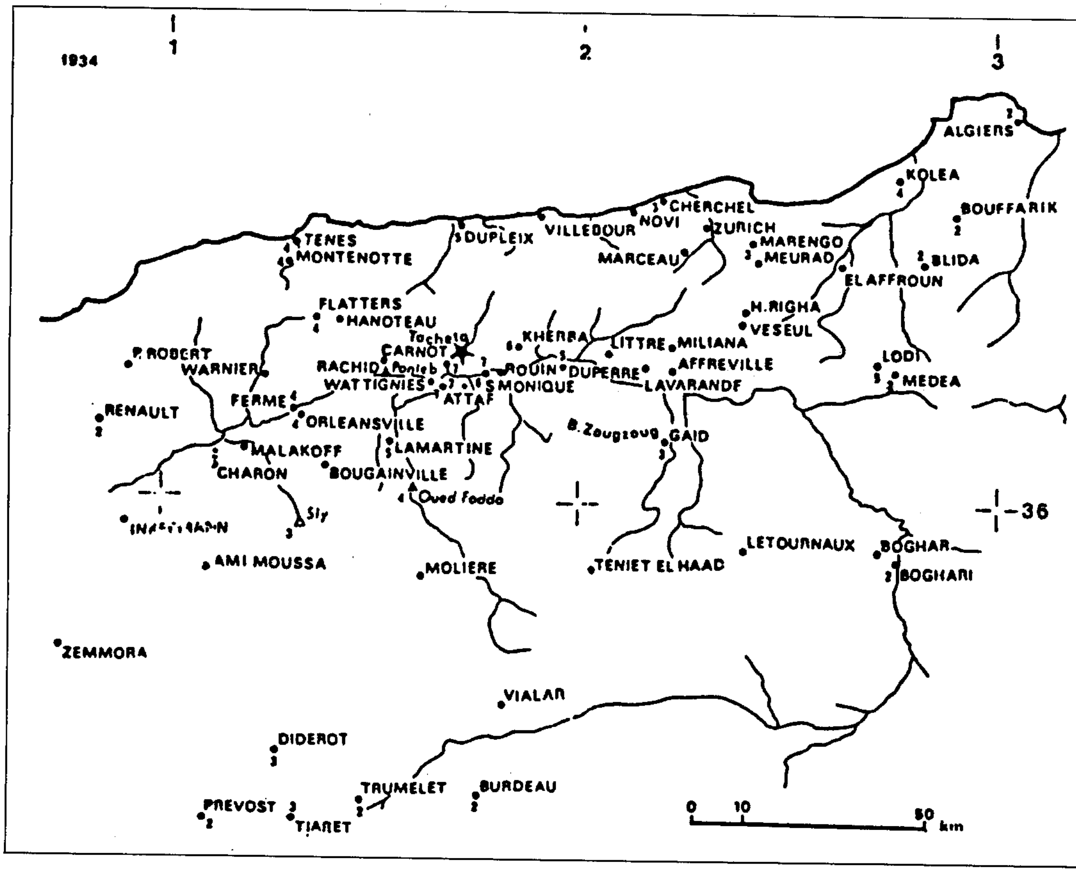

Fig. 2. Intensity distribution map of the main shock of 7 September 1934. The star shows the macroseismic epicentre. After Ambraseys *et al.* (1991a).

garding the effects of the earthquake in the most affected area. This earthquake was described only by few writers. Hée (1936b) described quite well the effects of this earthquake. She assigned intensities to various sites in the affected region, assigned a maximum intensity I_0 = IX (MCS) to the epicentral area within a radius of about 8 km and published an isoseismal map presented in fig. 1. Other authors have also assigned intensities to the most affected area: Ambraseys *et al.* (1991a) have allocated I_0 = VII (MSK) and assigned other intensities to various sites of the area (fig. 2), Rothé (1950) had attributed I_0 = IX (MM), I_0 = IX (MS) by Karnik (1969) and I_0 = IX (MSK) by Mezcua and Martinez (1983). Macroseismic epicentre has been located at 36.3°N, 1.7°E (Ambraseys *et al.*, 1991a), at 36.25°N, 1.7°E (Rothé, 1950) and at 36.2°N, 1.7°E (Karnik, 1969).

The earthquake of 7 September 1934 was recorded by most of the seismological stations operating at that time. Instrumental epicentral locations were assigned at 36.0°N, 2.0°E by Gutenberg and Richter (1965), at 36.2°N, 1.6°E by the ISS (1934) and at 36.23°N, 1.71°E by Mezcua and Martinez (1983).

In what follows, we present a summary

of the results obtained from the study of these documents and of the resultant damage of the event.

3. Damage and casualty distributions

The information collected from all the sources has been used in the re-evaluation of the damage and the estimation of the intensity. These data have greatly contributed to the reconstruction of the event and its impact on humans, man-made structures and the ground itself. All the sources give evidence on the destruction of the colonization village of Carnot and its surroundings.

Carnot, a small colonization village of 800 inhabitants, was almost totally destroyed by the main shock. Before dawn, at 3 h 39 min, when the shock hit the region, all the population panicked and flee from their homes while the buildings were wavering and collapsing. The soil was rumbling, the walls crashing, and the children and the women screaming of terror in the threatening darkness. The electrical cables were cut. The peasants were striving to take their panicked droves out the cattle-sheds. Many of the houses were reported destroyed and the remaining were seriously damaged. Damage was also reported as fall of ceilings, chimneys and inner walls in the area. The walls which were in the north or east orientation suffered more, they presented cracks in all different directions, particularly at their bases. It was reported that the water in the region showed a white colour during few days after the shaking and modifications of the water table level were observed. The earthquake triggered a number of landslides and rockfalls in the nearby mountains, caused slumping in the plain and damaged the roads in the north of the village, at Sidi Merzoug. At Carnot cemetery, soil was seriously cracked, graves were raised and nearby at approximately five hundred metres, a large crevasse of 200 m long, 2 m wide in some parts and 1.75 m deep was produced. Fortunately, many of the inhabitants, alerted by the foreshocks, were already in the open field when the earthquake struck the village; that is what may explain the lack of loss of life. However, 11 people were reported injured by the stones removed from the walls and the collapse of roofs. Eight kilometres south-east of Carnot, in the upper part of the plain, the colonization village of Saint-Cyprien experienced serious damage. Reports mention that the earthquake was strongly felt, causing the inhabitants to panic and to flee from their houses. Many houses collapsed and the rest were heavily damaged. It was reported that the Sainte-Elizabeth hospital suffered much damage and none of its buildings was spared. The most affected building was the central pavilion which contained the administration and the dormitory of the nurses. Walls and floors in the hospital were cracked, scores of chimneys and ceilings had collapsed and bricks were removed. The patients were taken out in the gardens and nursed under the trees but no one is reported to be killed or injured. It was also reported that the school and the post-office experienced damage such as: fall of chimneys, plaster, glass, and cracks in floors and ceilings. Casualty was either not reported or not communicated in this village. Nearby is the village of Les Attafs which is built on deep alluvial soil. Here also, the earthquake was preceded by a rumbling which caused the population to panic and to flee from their houses. During the shaking, the movement of the ground was observed to be rolling, in waves, from the west toward the east direction. The co-operative docks, where approximately 3000 tons of wheat were stored, had suffered much damage as well as the post office and the gendarmerie. These last constructions relatively well built, reinforced concrete or good masonry structures, give us a better idea of the size of the earthquake. Many houses, in the centre, were badly damaged and the old ones simply collapsed. It was reported that many free-standing walls, cornices and chimneys collapsed and most of the objects on shelves were ejected to the ground. The main water was muddy during many days after the shaking. A smell of sulphur was perceived in the region.

The villages of Sainte-Monique and Wattignies, where the shock was strongly felt, suffered considerable damage as reported. As in the other villages of the epicentral region, many of the inhabitants were all of a flutter and run outdoors to the open fields. No casualty was declared. It was reported that the inhabitants of Kherba, Duperre, La Ferme, Hanoteau, Flatters and Tacheta were frightened by the shaking and had to flee from their homes without even taking care of putting on their clothes. Slight damage was caused to these villages and no casualty was reported. In Dupleix, Gouraya, Miliana, Littre, Lavarande, Pont-Du-Caid, Bordj-Beni-Hendel, Bougainville, Orléansville and Warnier, the shaking caused minor damage as small cracks in walls and ceilings, but no alarm.

It was reported that, in the villages of Cherchell, Novi, Marceau, Zurich, Meurad, El-Affroun, Hammam-Righa, Vesoul-Benian, Affreville, Charon, Paul-Robert and Mentenotte, the shock was widely observed and awakened some sleeping people. Finally, according to many sources the perceptibility area of this event is limited by the following localities where the shaking was weak and partially observed: Alger, Dely-Brahim, Douaouda, Kolea, Souma, Blida, Lodi, Taza, Theniet-El-Had, Letournaux, Boghar, Boghari, Vialar, Trumelet, Bourlier, Tiaret, Diderot, Prevost-Paradol, Zemmora, Inkermann and Renault. We could find no evidence that the shaking was felt beyond these last mentioned villages.

4. Intensity distribution

Using the data retrieved from the various sources of information available to us, intensities were re-assessed with reference to the Medvedev-Sponheuer-Karnik (MSK) scale. The area of maximum intensity involves a zone of approximately 7 km radius, centred to the east of Carnot. It covers the villages of Carnot, Saint-Cyprien, Les Attafs, Wattignies and Sainte-Monique. This zone is well described by scientific works and newspapers. Broadly, maximum intensity was assigned to sites where many constructions were destroyed, rendered uninhabitable or heavily damaged and important ground features were produced. Intensity VI was allocated to the villages of Kherba, La Ferme, Hanoteau, Flatters, Tacheta and Duperre where panic and damage were observed. Intensity V was attributed to Dupleix, Gouraya, Miliana, Littre, Lavarande, Pont-Du-Caid, Bordj-Beni-Hendel, Bougainville, Orléansville and Warnier where panic and slight damage were reported. Intensity IV to Cherchell, Novi, Marceau, Zurich, Meurad, El-Affroun, Hammam-Righa, Vesoul-Benian, Affreville, Charon, Paul-Robert and Mentenotte where only felt effects were reported. Intensity III was assigned to the villages limiting the perceptibility area which extended to Alger (east), Boghari (south-east), Tiaret (south) and Zemmora (west). We found no evidence that the shaking was felt beyond these last named villages.

From the intensity data an isoseismal map has been drawn for the main shock and shown in fig. 3.

5. Magnitude determination

The surface-wave magnitude of the earthquake has been computed from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 9 seismograph stations located at distances between 4° and 52°, and a preliminary epicentre at 36.3°N, 1.7°E (macroseismic epicentre). The data and details are given in Benouar (1993). The mean period is 10 s, and the derived value of M_S, without station corrections, is 5.1 (± 0.2).

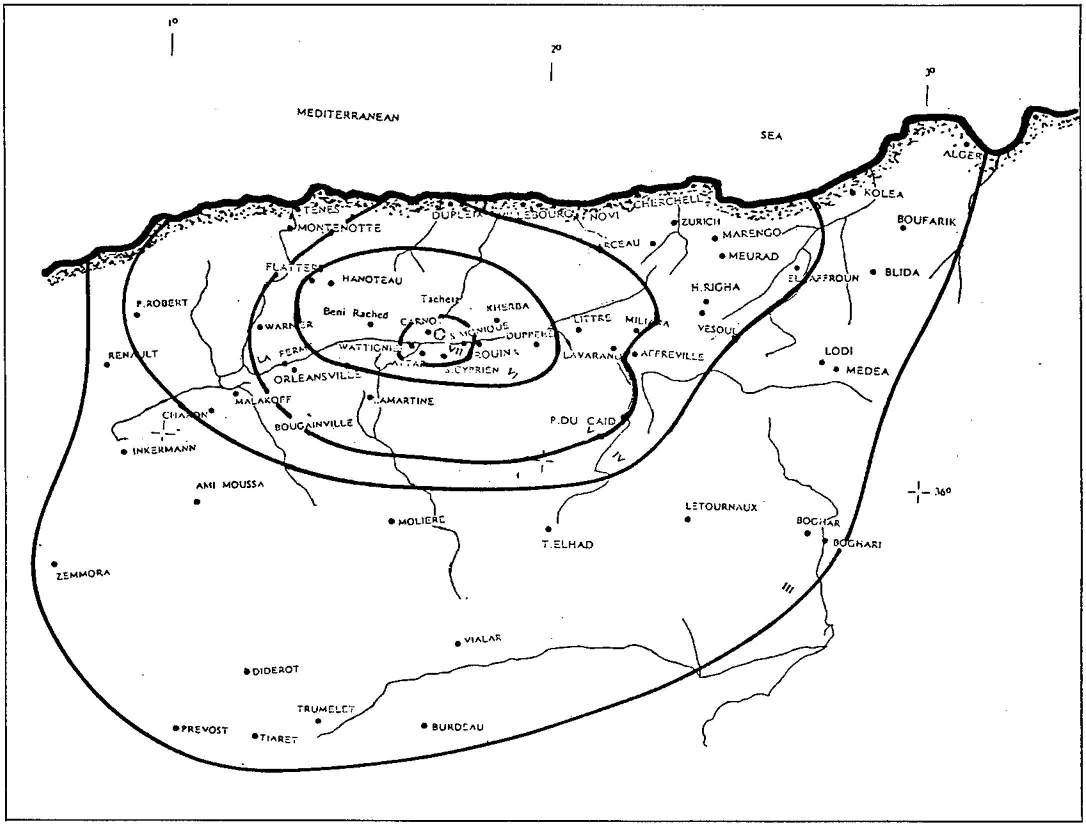

Fig. 3. Isoseismal map of the 7 September 1934 Carnot earthquake (main shock). The open star shows the macroseismic epicentre.

As for the main shock, the surface-wave magnitude for the largest aftershock of 7 September at 20 h 24 min has also been calculated, using teleseismic amplitude and period readings from 4 seismograph stations located at distances between 4° and 16°, and a preliminary epicentre at 36.3°N, 1.7°E. The data are shown in Benouar (1993). The mean period is 10 s and the derived value of M_S, without station corrections, is 4.5 ($\pm$ 0.17).

It appears therefore that the Carnot earthquake of 7 September 1934 was similar in size to the Cavaignac earthquake of 25 August 1922, which had $M_S = 5.1$ ($\pm$ 0.2) from 5 stations.

6. Foreshocks and aftershocks

The 7 September 1934 Carnot earthquake was preceded by few foreshocks and followed by a long sequence of aftershocks. Since July 1934, the seismic activity of the Cheliff Valley region increased considerably, particularly in the Orléansville-Malakoff zone where nine shocks were recorded or felt. Although these shakings did not occur exactly in the epicentral zone, they may be considered as foreshocks. Ten other shocks hit the Oued Fodda-Lamartine zone. The 5 September at 7 h 10 min a shock was felt particularly in Duperre and Rouina. The 6 September at 19 h 26 min another shock struck Carnot, Les Attafs, Rouina, Duperre, Marceau, Tenes, Littre, Pont-Du-Caid, Flatters, Kherba, Lamartine and La Ferme. Shocks continued to shake Les Attafs all the night. Finally, the 7 September at about 1 h (GMT), only two hours before the main shock, Les Attafs was shaken again. This sequence of foreshocks had alerted the population of the region. As it was reported, many people were sleeping in their gardens fearing stronger shocks and so saved their lives.

In the other hand, the earthquake was followed by a long sequence of more than one hundred aftershocks, continuing until November 1934. No injuries were reported, but reports said that they caused severe emotion among the population and added further damage to the weakened structures. Of the largest aftershocks, that of 7 September at 5 h 38 min caused some considerable concern to the inhabitants and was strongly felt at Les Attafs, Duperre, Dupleix, Cherchell, Marceau, Zurich, Meurad and Diderot. This shock was not recorded enough to allow an instrumental location and a surface-wave magnitude determination.

The largest aftershock occurred on 7 September at 20 h 24 min, it was strongly felt in Les Attafs and caused significant damage in Carnot (destruction of 25 houses) and in Affreville. The shock was widely recorded, the teleseismic data allow a surface-wave magnitude calculation from 4 stations which gives, without stations corrections, $M_S = 4.5$ ($\pm$ 0.17). The data and details are shown in Benouar (1993). Fewer authors have attributed some characteristics to this aftershock; Ambraseys *et al.* (1991a) assigned a surface-wave magnitude at $M_S = 4.6$ ($\pm$ 0.2) and a macroseismic epicentre at 36.3°N, 1.7°E; Karnik (1969) gave $M_S = 4.5$ and macroseismic epicentral location at 36.2°N, 1.7°E; the ISS gave an instrumental solution at 36.0°N, 1.1°E.

7. Discussion

Although it is impossible at this stage to assess in details the effects of this earthquake in each site of the felt region, it is shown from the retrieved macroseismic data that the size and the impacts of this event have been over-estimated by some authors (Hée, 1936b; Rothé, 1950). After much consideration and analysis of the various types of retrieved data, maximum intensity has been re-estimated at I_0 = VII (MSK). The zone of maximum intensity covers an area of approximately 7 km radius, centred to the east of Carnot. Giving the topography, the geology and the types of constructions of the region, the size of the affected zone is consistent with the range over which a magnitude 5.1 earthquake is likely to exhibit effects corresponding to an intensity of about VII (MSK). The Cheliff Valley, in 1934, was relatively sparsely populated with no large towns and the douars were scattered on the surrounding mountains. We believe that the douars sustained much more damage and casualties, but they are not mentioned in any report available to us. This perhaps explains the reason why human losses and damage details are not clearly reported. At that time, officials reports rarely publish unbiased loss statistics for the natives. To appreciate better the importance of the earthquake and the information available in the contemporary sources, the knowledge of the historical, socio-economic situation, cultural and religious backgrounds, and the characteristics of the constructions is essential for an appropriate re-evaluation of the impact of the event. The year of the earthquake, 1934, corresponds to a politically and economically unstable period in Algeria and the Maghreb as a whole. That period is marked with several uprisings of the native population in the Maghreb countries. In 1934, the pana-islamism movement, which started after the muslim congress in Jerusalem (1931), and the nazi Germany ware calling the Maghreb people for insurrection against the French presence. The Cheliff Valley was also hit by a serious depression.

In circumstances like those of colonized countries, lack of critical analysis of historical sources of both communities will lead definitely to gross misjudgment of the impacts of the earthquake.

Summarizing the results, we obtain the following final data for the 7 September 1934 earthquake: origin time (GMT) 3 h 39 min 24 s; instrumental epicentre at 36.2°N, 1.6°E (ISS); macroseismic epicentre at 36.3°N, 1.7°E; focal depth of about of 10 km; maximum intensity I_0 = VII (MSK); magnitude M_S = 5.1 (± 0.2).

The Guelma earthquake of 10 February 1937

Abstract
This research examines one of the largest earthquakes in Guelma during the last two centuries. The Guelma earthquake of 10 February 1937 occurred at 8 h 14 min 38 s (GMT); it is the strongest seismic event felt and recorded in the Guelma region. The main shock, which lasted about 15 s, caused the loss of 2 lives, injured at least 16 and made numerous people homeless; it destroyed or heavily damaged several housing units and public buildings. The cost of the damage was estimated at more than 5 million French Francs. The radius of perceptibility was not really large, the shock being felt in Tabarca (Tunisia) 130 km away. The earthquake was recorded as far as Vladivostock, 9550 km away. The main shock was preceded by a foreshock at 6.00 (GMT) on the same day and followed by a series of aftershocks, with one strong enough to cause additional damage in the affected zone. Critical study of the contemporary documents relative to this event has led to the macroseismic field reconstruction and thus to the re-assessment of the strength of the ground shaking. Intensities are re-evaluated at 48 sites and an isoseismal map has been drawn. Maximum intensity has been re-evaluated at I_0 = VIII in the MSK scale, assigned to Lapaine and Bled Gaffar and covers an area of about 9 km radius. The earthquake was associated with slight landslips and slumping. There is no indication of any sign of liquefaction in the affected zone. The instrumental epicentre has been relocated, using the present ISC location procedure and readings from 26 seismological stations, at 36.4°N, 7.2°E. The macroseismic epicentre has been located slightly east of Lapaine at 36.388°N, 7.525°E. The surface-wave magnitude has been calculated, without station corrections, at 5.20 (± 0.22).

1. Introduction

On Wednesday 10 February 1937, at 8 h 14 min 38 s (GMT), a destructive earthquake struck the region of Guelma, located about 390 km east of the capital, Alger. It occurred very near to where early destructive shocks in 1908 and 1928 caused major damage to the same epicentral zone, particularly to Lapaine, therefore this earthquake is by no means an unprecedented one. The main shock, which in Guelma lasted about 15 s, caused the loss of 2 lives, injured 16 and rendering several people homeless; it destroyed numerous traditional houses (gourbis), colonial houses and farms, as well as public buildings. The epicentral area, within which the shock caused heavy damage and casualties, accommodated about 13000 people living in around 2000 housing units (Armature Urbaine 1987, 1988). The earthquake was seriously felt in the eastern part of the Constantine Department (Province) and as far as Tabarca in Tunisia. The main shock was recorded by 35 seismological stations in the world (ISS, 1937), up to Vladivostock 9550 km away. The earthquake was preceded by one foreshock at 6.00 (GMT) on the same day and followed by a series of aftershocks, with one strong enough to cause additional damage in the affected area. The main shock affected structures within an area of about 52 km radius. Most damage was observed in Lapaine and Bled Gaffar. The earthquake was associated with slight landslips and slumping. It was reported that the flow of the hot springs of Hammam Meskhoutine increased considerably.

Collection and critical study of the contemporary documents relative to this event has led to a detailed re-estimation of the amount of damage caused to man-made structures and to nature, and how the population behaved. As in past earthquakes in Algeria and elsewhere, adobe, drystone and unreinforced masonry constructions experienced collapse or heavy damage. The macroseismic information retrieved has allowed us to re-evaluate intensities in 48 sites. Maximum intensity has been re-estimated at I_0 = VIII (MSK), allocated to Lapaine and Bled Gaffar and covers an area of about 9 km radius. The instrumental epicentre was recalculated, using the present ISC procedure, at 36.4°N, 7.2°E. The macroseismic epicentre has been relocated slightly east of Lapaine and Bled Gaffar, at 36.388°N, 7.525°E. Teleseismic amplitude and period readings from 10 seismological stations were used to calculate the surface-wave magnitude which is, without station corrections, 5.20 (± 0.22).

2. Sources of information

Despite its importance in the region, however, there is only one report which is really known and available to us; it is that of Hée (1937). The main sources used by this author are direct reports from teachers in the whole felt zone. Hée (1937), in a special note, adequately described the effects of the earthquake on the whole felt region and assigned intensities to different sites. She allocated maximum intensity IX (MS) to Lapaine, Bled Gaffar and the Dimeck farm. Rothé (1950), quoting Hée as his source, summarized briefly the effects of the earthquake on the region, allocated maximum intensity at I_0 = VIII (MS) and published an isoseismal map (fig. 1). This earthquake was widely reported in the Algerian and French newspapers (1937) because of the severity of the damage caused, particularly to the French settlements. The most comprehensive account is given in «La Dépêche Algérienne» which contains detailed macroseismic information, accompanied with photographs which show clearly the extent of the damage. Other authors have also reported the event Karnik (1969) and Rothé (1950) assigned maximum intensity at VIII (MS) and calculated the surface-wave magnitude at 5.3. Mezcua and Martinez (1983), referring to the IPGA, allocated a maximum intensity at VIII (MSK) to Lapaine; he calculated the body-wave magnitude (m_b) at 5.4. In spite of the size of the event, Gutenberg and Richter (1965) did not mention it. The instrumental epicentre was located at 36.6°N, 7.5°E by the ISS. Macroseismic epicentre location was given at 36.4°N, 7.5°E by Rothé (1950) who is repeated by Karnik (1969), and Mezcua and Martinez (1983).

3. Geographical aspects of the region

The epicentral region is located in the eastern part of the country, at about 390 km east of the capital Alger and 70 km southeast of Constantine. Guelma, which in antiquity was called Calama, existed before the Roman conquest. The region of Guelma has always been an important site for different civilizations and should therefore have a long and well-recorded history. Research into the cultural background of the region would certainly reveal previous earthquakes of magnitude equivalent to, or greater than, the 1937 earthquake. The basin of Guelma, limited in the north by the Taya ranges and Djebel Debar, contains a series of narrow depressions which spread out along the Seybouse Valley, from Oued Zenati to Duvivier. The mountainous

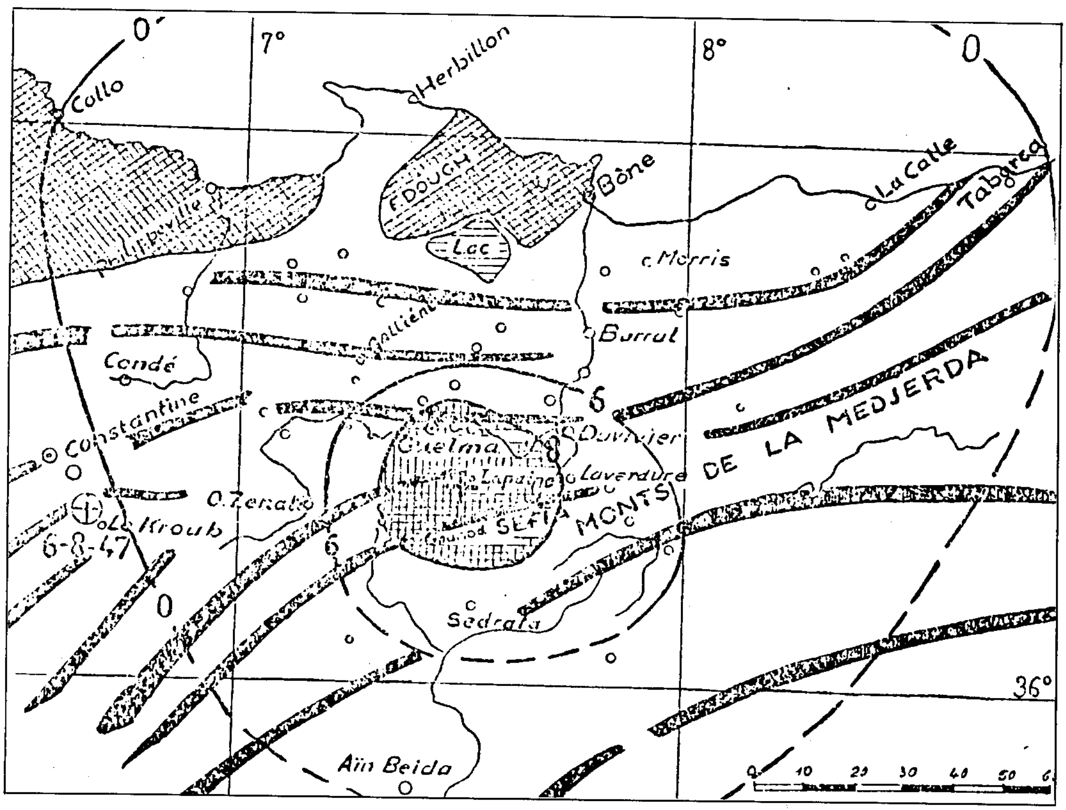

Fig. 1. Isoseismal map (MS scale) of the main shock of the 10 February 1937 earthquake, after Rothé (1950).

massifs which enclose this basin are mainly constituted of sandstone; they are well wooded in the area surrounding Taya but become barer as the plain is approached. The meridional part is characterized by the Mahouna massif (1411 m) which, towards the east, merges with those of Souk Ahras. The Basin of Guelma, 200-250 m high, is separated from the plain of Bone by smooth low hills which, with their vegetation, make it part of the littoral zone of the Tell. Due to its agricultural vocation (oil works, cultivation of vegetables and fruits), the region has provided good conditions for many civilizations.

4. Damage and casualty distributions

The earthquake, preceded by a slight foreshock at 6.00 (GMT), occurred at 8 h 14 min 38 s. It was centred about 12 km southeast of Guelma. The epicentral zone, within which the earthquake caused heavy damage, accommodated about 13000 people, of whom 12000 were native Algerians. The typical constructions prevailing at that time were adobe and drystone houses (gourbis) for the natives and unreinforced masonry for the others. The main shock, which lasted 15 s in Guelma, killed at least two people, injured more than 16 others and made numerous more homeless; it destroyed several houses, farms and public edifices. Detailed study of the macroseismic information collected has substantially contributed to the re-assessment of the damage and casualties caused by this earthquake. The earthquake caused heavy to slight damage in an area about 50 km radius. All the sources give evidence of the destruction of Lapaine and Bled Gaffar and the immediate vicinity of these localities. In Guelma the main shock, which lasted 15 s, was accompanied by a violent, deafening rumbling. The oscillations were in the ESE-WNW direction. The shaking was strong enough to cause the population to panic and flee from their homes to the streets and public gardens, fearing another strong shock. People were seen running in different directions to the schools looking for their children. As it was reported by the press (1937), only very few buildings were unaffected in Guelma itself. The most badly damaged buildings were certainly the Royal Hotel, which was completely evacuated, and the Bonan buildings, located in Saint-Augustin Place. In the apartment block buildings of the Compagnie Algérienne and those of Mr. Ch. Zuretti, more than 20 ceilings and 10 partition walls sustained heavy damage and had to be rebuilt. The buildings of the city hall, the mosque, the theatre, the Sevigne school and the native girls' school were heavily damaged and were repaired at high cost. The large building in front of the post office had its parapet destroyed and interior walls in the third storey were so seriously damaged that they had to be rebuilt completely. The earthquake was strong enough to topple several chimneys. The prison sustained so much damage that the prisoners, in total panic, rushed for the door, trying to flee outdoors. The earthquake was associated with slight landslides, about 19 km away on the road of Sedrata, which was closed to traffic. The main water pipe, which used to supply the city of Guelma, was broken, and consequently created a serious problem for the inhabitants. Lapaine (Commune mixte of Oued Cherf), a small colonial village, is located at 17 km southeast of Guelma. It was reported that the whole village was razed to the ground, and offered a heartbreaking scene. The main shock, which lasted about 15 s, caused the loss of 2 lives, injured at least 16 and rendered 28 families homeless (12 French and 16 native Algerians); it practically destroyed all the housing units and public buildings. The school building, which was a remarkable construction, with its large balconies and balustrades, was also in ruins. The post office was also seriously damaged. In the douar of Kheszara, in the close vicinity of Lapaine, the earthquake destroyed most of the native houses, seriously damaged the colonial buildings and produced rockfall and slight surface ground fissures (Press, 1937). Lapaine is known to have been seriously affected during the 1928 Guelma earthquake. The press (1937) reported that the French population did not have any shelter except one very recent construction which did not suffer much, but there was no report about the natives. The villas, which were full of life and charm, were no more than a heap of ruins of plaster, bricks, debris of furniture, pieces of marble and glass. Bled Gaffar (Commune of Petit), a very small village located at about 11 km southeast of Guelma, offered the same spectacle as Lapaine. The shaking was so strong that all the inhabitants fled their homes and it was seriously felt by the people outdoors. The shock was preceded by a deafening underground rumbling. The oscillations were, first, horizontal from north to south and then vertical from bottom to top. Most of the buildings were rendered uninhabitable, the exterior walls were seriously cracked, the partition walls crashed down, the chimneys collapsed and the roofs were heavily damaged. The whole village looked as if it had suffered a heavy bombardment. The school buildings were more badly affected than those in Lapaine. The teacher's apartment, located in the second floor, was completely destroyed and the furniture was broken by the collapse of the partition walls. The classrooms were full of debris of plaster, bricks and jumbled furniture. The children were evacuated via the windows, since the doors were obstructed by the debris. Witnesses reported that: «Looking at the extent of damage in the classrooms, it was a miracle that the children were not hurt». The school was temporarily transferred into the chapel, the construction which had suffered least in this locality. It was reported (Press, 1937) that: «if the villas of the Richardot were still standing, it would be wise to demolish them as quickly as possible». In the surroundings, no farm resisted the earthquake; all were heavily damaged or totally destroyed. Six kilometres from Bled Gaffar, in Oued Maiz, the Dimeck farm was no more than a pile of ruins. In the vicinity of Mahouna, the farms Ganci, Bonan, of the Caid (douar chief), Saint Andre, Bezzina... etc., all displayed a distressing aspect. In Gounod, located at 21 km south of Guelma, the shock was violent. It was preceded by an underground rumbling which was followed by a deafening noise. The oscillations were in the southeast-northwest direction. Many native houses were completely destroyed but there were no injuries or casualties among the population. Numerous cracks were observed in the bearing walls of the relatively well built colonial constructions. Six kilometres away, a hot spring became dry and then threw out thick reddish water. In Millesimo, 5 km east of Guelma, the shaking was characterized by a slow swaying in the east-west direction. The population reported that they heard a rumbling similar to that produced by a passing heavy truck. The ground motion was not violent in the village itself but a worker who was surveying the public works field, 2 km away on the road between Guelma and Sedrata, had seriously felt the oscillations and reported that he had the impression that the road was subsiding under his feet (Hée, 1937). The same worker reported that he has seen the farms of the area falling in ruins (Hée, 1937). The bell tower of the school was loosened and slightly bent in the south-southeast direction. In the village and its close surroundings the walls were all cracked. In Petit, a small colonial village located at 8 km east of Guelma, serious damage was observed in the city hall, the school and in many houses. The houses suffered so significantly that they had to be evacuated (Press, 1937). Fall of chimneys were also reported in the village and its surroundings. A deafening noise was heard before the shaking. Heliopolis, 6 km north of Guelma, is located further to the north than the former sites and on the other bank of the River Seybouse. The oscillations were strongly felt. An underground rumbling was heard in the area before the main shock. The walls were deeply displaced and two houses were completely destroyed. In the school a freestone column and a wall collapsed and the furniture was overturned (Hée, 1937). Concerning the damage caused to the native houses, it was reported by the press (1937), as a journalist said: «... we cannot mention the considerable damage sustained by the native constructions...»; this subject has been discussed in section 1. Chapter I. In Kellermann, 7 km west of Guelma, the vibration was brusque and in the vertical direction. Much of the damage, which consisted of small cracks in walls, fall of large pieces of plaster and cracks in chimneys, was caused to the colonial constructions. On the other hand, the native houses sustained such heavy damage as large and deep fissures in walls. In Hammam Meskhoutine (city of Clauzel), hot springs located about 14 km east of Guelma, the sensation of the vibration was like due to the passing of a heavily loaded truck. It was reported that the flow of the springs had increased considerably. Moderate damage, which consisted of small cracks in the walls and fall of plaster, was observed in most of the houses in the area. A limestone crest, very close to the settlement, was fissured all-over its length. In Laverdure, located at 35 km southeast of Guelma, more than 50 houses were seriously damaged, but no details were available (Hée, 1937). In

Zarouria (city of Souk Ahras), 50 km southeast of Guelma, the shaking was felt by most of the population and described as a slow swaying. It was reported that a few fissures were observed in some buildings. In Souk Ahras, 45 km southeast of Guelma, the shaking was felt by all the population. It was preceded by an underground rumbling. The main shock, which lasted 2 s, caused the displacement of furniture in the houses. Bells were reported to have rung. In Villars (city of Sefia), located at 30 km east of Guelma, there was no severe shock but vibrations were felt. A pendulum clock, which had stopped 5 years before, started running again after the earthquake. In Duvivier, situated at 25 km east of Guelma, the shock was intense. The oscillations appeared to go from north to south. A few existing fissures in the walls were accentuated. A pendulum clock, in the second storey, stopped at 8 h 21 min (GMT). Fauvelle (City of Sefia) experienced a slow swaying. In the school a few fissures were produced in walls which were in an advanced state of decay. In Ain Seymour, 40 km southeast of Guelma, the shaking, which was felt by all the population, was accompanied by an underground rumbling. Bells were reported to have rang. In Sedrata the swaying was like the rolling of waves at sea and was felt by all the population. In Gallieni, located at 18 km northwest of Guelma, only vibrations, which were preceded by an underground rumbling, were felt. Furniture was reported to have been displaced in many houses. The flow of the spring of the village had increased slightly (Hée, 1937; Press, 1937). In Saint Joseph (city of Edough), 30 km northeast of Guelma, slow swaying and vibrations were observed. An underground noise was heard during the shaking. In Nemchaya a slight swaying was felt. In Barral (city of Bone), 40 km northeast of Guelma, the shaking was perceived indoors by all the population but outdoors only by very few. Cracking of tiles, ceilings, walls and wooden floors were heard in the area. In spite of the distance from the epicentre, the intensity of the shaking was strong enough to cause fissures in walls. However, we believe that the fissured walls were in an advanced state of deterioration through ageing and lack of proper repair. In Ain Saint Charles (city of Clauzel) the vibration was brusque. The oscillations were from east to west in direction and were preceded by an underground rumbling. The blackboards in the school all tilted in the same direction. Numerous cracks were produced in the walls of the buildings. In Lamy, 60 km east of Guelma, the vibrations were in the east-west direction. Small fissures, without any significance, were observed in walls. The water in the springs of the area was muddy and discoloured. On the route between Lamy and La Calle a few landslides, due to the clayey nature of the soil, took place (Hée, 1937). In Mondovi the oscillations were in the south-west direction. An underground rumbling preceded the main shock. Small cracks were observed in the ceilings. In Duzerville the swaying was very rapid. In Penthievre the shock was in the vertical direction. A few small cracks were reported in ceilings and old walls. In Combes (city of Edough) the swaying was brusque and accompanied by noise. Existing cracks expanded in the houses near the school. In Ain Mokra, 55 km northwest of Guelma, an underground noise was heard before the shaking. Swaying and vibrations were perceived and a few small fissures were produced in walls and ceilings. In Morris a brusque shock and vibrations were felt. The shaking, which was in the southwest-northeast direction, was felt indoors by all the population and outdoors by many. The bell of the clock rang four times and bottles fell from the shelves. In the school stoves and pipes were seriously shaken. In Oued Zenati the shaking was felt by a few people. In Sedrata the swaying was like the rolling of waves at sea and was felt by all the population. In Randon slow swaying in the southeast-northwest direction was reported. The shaking was strong enough to displace various objects such as blackboards and damage furniture. In

Bone, 60 km northeast of Guelma, the shaking was seriously felt. A fissure of about 10 cm was produced in the buildings of the military hospital. An underground rumbling was heard during the shaking. In Phillipeville, located at 65 km northwest of Guelma, the main shock, which lasted between 8 and 10 s, caused oscillations in the west-east direction. Among the numerous members of the faithful attending the Ash Wednesday mass, many rushed outdoors in a total panic though no damage was declared. In Jemmapes the shaking was of very short duration creating swaying and vibrations. It was felt in the city itself and in all the surrounding centres: Gastonville, Auribeau, Roknia, La Robertseau, but no damage was reported. In Bugeaud the swaying was slow and accompanied with a rumbling. It was strong enough to make the window panes vibrate. In Herbillon the vibrations were slightly felt. The sea became suddenly rough. The shaking was felt as far as the semaphore of Cap de Fer 35 km away. In Lannoy (city of Jemmapes), the shaking was felt indoors only. In Stora, 70 km northwest of Guelma, the shaking was felt by all. In Gatsu the shaking, which was accompanied by a deafening noise, produced vibrations. Boudaroua (city of Edough) experienced swaying and vibrations. Damage consisted of fall of plaster and small cracks in the walls. In Le Tarf (city of La Calle), vibrations of the window panes were reported. In Collo slow swaying was observed. In Conde-Smendo the shaking was characterized by vibrations in the north-south direction and plates and dishes were shaken. In La Calle, located at 105 km north of Guelma, the swaying was slow. In Tabarca (Tunisia), situated at 130 km northeast of Guelma, the shaking was slightly felt. In Collo and Ain Beida, slight shaking was reported. We found no other evidence that the shaking was felt beyond Tabarca in the east, Collo in the west and Ain Beida in the south. Many other sites were mentioned by Hée (1937), within the radius of perceptibility, but without any felt details.

5. Intensity re-evaluation

The intensity was re-evaluated, using all the macroseismic information retrieved from the different sources available to us, with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale.

To re-estimate the strength of the ground shaking with an appreciable degree of reliability, an extensive search for the contemporary documents relative to this earthquake was carried out. Study and critical analysis of the macroseismic data collected has led to a detailed re-assessment of how much damage was inflicted to humans, man-made structures and to the ground itself. The building stock exposed to the earthquake, which was characterized by adobe, drystone and ordinary masonry, sustained important damage. According to certain sources, many of these houses were in an advanced state of deterioration, suffering through ageing, negligence, rain, earthquakes and lack of proper repair. The majority of these dwellings were already affected during the 1908 and 1928 Guelma earthquakes and so they had been repaired more than once.

As a consequence of the defective nature of these structures, the maximum intensity in any destructive earthquake in the different villages and douars would appear to be the same. That is, at intensity IX in the MSK scale, most of the houses would be totally destroyed and any douar would thus look equally, but no more, devastated at higher intensities of the scale. After much analysis of the reconstructed macroseismic field, maximum intensity was re-estimated at I_0 = VIII (MSK), allocated to Lapaine and Bled Gaffar, an area about 9 km radius. It was assigned to the sites associated with maximum damage such as collapse of structures, ground deformations and loss of life. Intensity VII was confined to Gounod, Millesimo, Heliopolis, Petit, Kellerman, Guelma, Laverdure, Villars, Duvivier and Hammam Meskhoutine. Intensity VI was attributed to Ain Saint Charles, Sedrata,

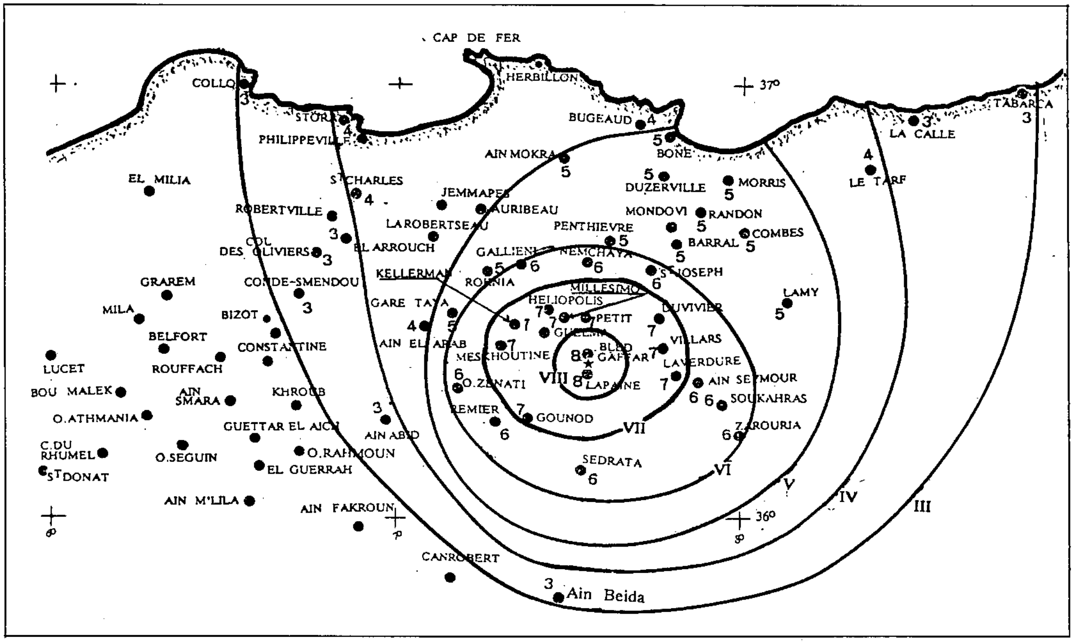

Fig. 2. Isoseismal map (MSK scale) of the main shock of the 10 February 1937 earthquake. The star shows the macroseismic epicentre of the main shock.

Zarzouria, Souk Ahras, Ain Seymour, St-Joseph, Nemchaya, Gallieni and Oued Zenati. Intensity V was allocated to Barral, Combes, Randon, Ain Mokra, Morris, Duzerville, Penthievre, Bone, Roknia, Gare Taya and Lamy. Intensity IV was attributed to Le Tarf, Phillipeville, Gastonville, Jemmapes, Stora, Saint-Charles, La Robertseau, Bugeaud, Herbillon and Cap De Fer. Intensity III was assigned to Le Collo, Conde-Smendo, Ain Beida, La calle and Tabarca. Intensities V to VII were assigned with a rigid interpretation of the MSK intensity scale (Medvedev *et al.*, 1981). Intensities III to IV were attributed mainly on felt effect and on the evidence of lack of damage to poor-quality constructions.

As a result of the analysis of the macroseismic data, an isoseismal map of Guelma 10 February 1937 earthquake has been drawn and is shown in fig. 2.

6. Magnitude determination

We have calculated the surface-wave magnitude of the earthquake from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 11 seismological stations located at distances between 15° and 86°, and a preliminary epicentre (macroseismic) at 36.388°N, 7.525°E. The data and the result are presented in Benouar (1993). The mean period is 14.5 s and the derived values of M_S, without station corrections, is 5.20 ($\pm$ 0.22).

7. Teleseismic relocation

We have determined the instrumental epicentre of the earthquake using the present location procedure of the International Seismological Centre and readings from 26 seismological stations that reported the event to the ISS. The main shock was recorded through Europe as far as Sverdlovsk 41° away, also reported by Ksara (Lebanon), Helwan (Egypt), Alger (Algeria) and Tunis (Tunisia) which is the closest. Most of these reporting stations were in Europe, so they were all to the north, resulting in a poor azimuthal distribution of stations around the epicentre. Stations with large residuals have been weighed small or left out of the analysis.

With a trial origin consistent with the maximum reported experienced effects (36.6°N, 7.5°E) and using the present ISC procedure, we find:

1937 February 10
8 h 14 min 38 s (± 2.3)
36.4°N (± 0.24), 7.2°E (± 0.20)
Shallow focus 6 km.

This position agrees with the macroseismic epicentre with errors of about 1.3 km in latitude and 36 km in longitude.

8. Foreshocks and aftershocks

According to Hée (1937), the earthquake was preceded by one slight foreshock with intensity IV (International Scale) at 6.00 (GMT) the same day. On the other hand, the main shock was followed by a long series of aftershocks, with one of comparable magnitude.

The strongest aftershock occurred on 13 February 1937 at 2 h 28 min (GMT). It was strongly felt in the affected area as far as La Calle 130 km away. The intensities were estimated, using all the data available for this aftershock, with reference to Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale. These intensities are mainly assigned on felt effects reported, particularly, in the Algerian press reports. In Guelma this aftershock was so strong that the majority of the population was awakened and fled their homes to the streets and the Place Saint Augustin. This shock, which was shorter in duration than the main shock, was accompanied by a deafening detonation. It caused new small cracks in many structures but no casualties were reported among the population (V). In Lapaine and Bled Gaffar scores of sections of walls and ceilings, already damaged during the main shock, collapsed completely (V). In Petit and Heliopolis the shock was felt by all (V). In Nador and Saint-Charles partition walls were seriously shaken (IV). In Souk Ahras, Penthievre and Boudaroua the shaking was strong enough to make the population anxious for the rest of the night. It had seriously shaken the buildings in the region but no damage or casualties were reported (IV). In Ain Mokra the shock was felt by all the inhabitants and caused a bell to ring (IV-V). In Bugeaud and Bone it had seriously shaken the buildings and frightened the inhabitants. It caused cracking of furniture and fall of objects hanging on walls (IV). In Lamy the shaking was felt by all (IV). In Phillipeville many people were awakened (IV). In El Arrouch it caused the vibration of window panes (IV). In Jemmapes the shaking was seriously felt and accompanied by an underground rumbling, but no damage or casualties were reported (IV). In La Calle the shaking was strong enough to make the population anxious for the whole night (IV). This earthquake was also strongly felt in the regions of Oued Zenati, Ain Amara and Clauzel. The steeple of the church in Clauzel threatened to collapse (V). A flour mill in Ain Amara was damaged (V). This aftershock was slightly felt in Constantine, Conde Smendou and Catina (III). The amount of the macroseismic data so far collected does not allow us to locate the epicentral area of this aftershock any better than is shown by high intensities in fig. 3: a zone between Heliopolis, Petit, Guelma, Ain Amara and Lapaine. The instrumental data of this shock are also insufficient to allow an instrumental location.

Of the largest aftershocks, were those of Duvivier on 10 February at around 20 h

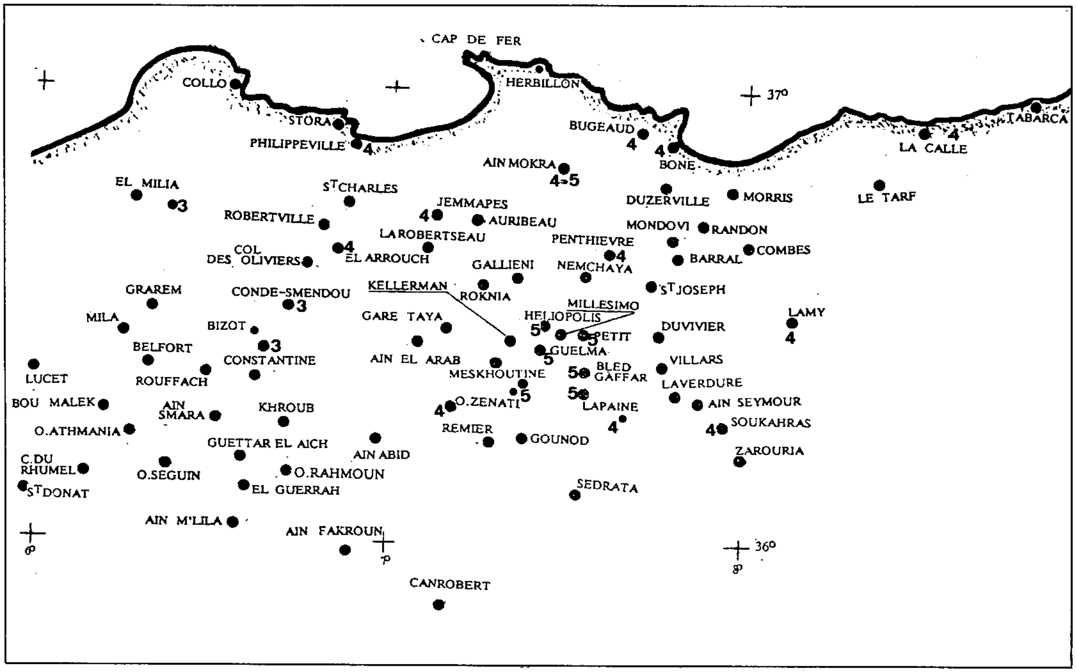

Fig. 3. Distribution of intensities (MSK scale) of the largest aftershock of 13 February 1937.

which lasted a few seconds and Guelma on 13 February at 2 h 55 min, 14 at 0 h 30 min and 7 h; 15 at 7 h, 12 h and 16 h; 17 at 2 h and 6 h, 21 at 14 h 10 min and 27 March at around 4 h 15 min. Some other aftershocks were felt in Gallieni on 15 February at about 23 h, 17 at 6 h and 26 at 3 h and 5 h.

9. Discussion

The Guelma 10 February 1937 earthquake is one of the largest seismic events that ever occurred in the region. In terms of the seismic history of the Guelma region reported by Cheseau (1892), Hée (1923, 1950) and Rothé (1950), two destructive earthquakes struck Guelma in this century. These earthquakes are those of 17 June 1908, which was felt at Guelma with intensity VII-VIII (MS) and 3 December 1928 which destroyed many houses in Lapaine and its surroundings. Therefore, the 1937 Guelma earthquake was by no means an exceptional one. This event shows the potential for a higher degree of time and space inhomogeneities of seismicity in the Guelma region and the consequences of this in the evaluation of seismic hazard in Algeria.

The reconstruction of the macroseismic field of the 10 February 1937 earthquake is of great importance for various reasons. First, it represents the strongest felt and recorded seismic event in the Guelma region in this century. Second, the same epicentral area which, as far as we know, experienced destructive earthquakes in the past (1908 and 1928), displays today many of the human and geographical characteristics (densely populated and urbanized) found in other parts in Northern Algeria. For these reasons, a detailed study of the effects of this event on the humans, made-made structures and on the ground itself, is pertinent to the whole country, in terms of seismic hazard and risk evaluations. It provides a fundamental mean for the reduction of future seismic disasters by suggesting new ways of improving local construction procedures, building materials, strengthening and properly repairing existing structures, layout and implementation of new urban and rural settlements.

As in other past earthquakes in Algeria, we have remarked the ease with which local traditional houses and even the ordinary masonry colonial buildings were destroyed or damaged. These dwellings, which were one storey high, were of mud-straw, drystone or adobe brick bearing wall construction, covered with a heavy thatched roof. Generally, they are partially below street level, the ground inside having been used for making materials with which the house was built, enlarged or repaired. They are generally built very close together in clusters, separated by narrow winding alleys. A general conclusion that may be drawn about the typical native housing units is therefore its inherent strength is very low and variable and its vulnerability extremely high. Thus, as a consequence of the fragility of the building stock exposed to the shaking, the maximum intensity in any destructive earthquake in the region would appear the same. That is, at intensity IX in the MSK scale, all adobe, mud and drystone dwellings would be destroyed and any douar would look equally, but no more, devastated at higher intensities of the scale. For this reason and after critical analysis of the macroseismic data collected, maximum intensity was re-evaluated at I_0 = VIII (MSK) and allocated to Lapaine and Bled Gaffar, an area about 9 km radius.

However, for a wise analytical study of past earthquakes, and better understanding of the information contained in the contemporary sources, one should take into account the political, socio-economic and demographic conditions, cultural and religious background and the building stock characteristics of the period concerned. The earthquake seriously affected the basin of Guelma, which was one of the most important colonization zone. The region, which was characterized by its fertile soil, important water resources and climate, attracted many settlers and natives. The French administration, in accordance with the long history of the region, made of it an important agricultural colonial settlement. Due to its importance, and the damage caused to numerous farms, the General Governor of Algeria visited the affected region to calm the fears of the settlers, who were thinking of abandoning the region, and show the government's concern. For these reasons, the earthquake was widely reported in the Algerian and French press. On the other hand, we believe that damage and casualties among the natives were certainly higher, because of the fragility of their dwellings, but details were not communicated. Sparsely distributed douars in many intermediate colonial villages within the radius of perceptibility, which could have enriched the data, were not mentioned by name. The information in the press was limited to colonial villages and towns where interest in the press was expressed (Vogt, 1993). As in previous events of a similar kind, the French authorities reported the information in the best way to show security and stability for the settlers. At that time, official reports rarely communicated loss statistics for non-european settlements (see section 1. Chapter I). This fact is clearly shown in the «Echo d'Alger» (1937) as a journalist wrote: «... we cannot report the damage in the native settlements, which is considerable...», but no interest was expressed by the administration (Vogt, 1993). The negligence of the administration, with the idea of minimizing the earthquake threat to the settlers, may explain the reason why property and human losses seemed disproportionately small for an earthquake of this size in an area of poor-quality construction. We believe that the exact casualty toll may never be known, as many victims, buried immediately to conform to the Islamic law, were either not reported, or simply ignored by the French administration. In similar situations, more important and complete information can be inferred from contemporary military sources which, unfortunately, are not available to us today. These documents, because of their official character, contain ample and reliable data. This study constitutes a major improvement in knowledge of many details of the event. The search for additional details of the extent of damage and casualties in the whole affected area continues.

Summarizing the results, we obtain the following final data for the 10 February 1937 earthquake: origin time 8 h 14 min 38 s (GMT); instrumental epicentre at 36.4°N, 7.2°E; macroseismic epicentre at 36.388°N, 7.525°E; focal depth about 6 km; maximum intensity I_0 = VIII (MSK); magnitude M_S = 5.20 (± 0.22).

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The Mansoura earthquake of 16 April 1943

Abstract
This research examines one of the most significant earthquakes in the central eastern part of the Tell Atlas in the Bibans ranges. On april 16, 1943, at 11 h 43 min 14 s (GMT), a destructive earthquake struck the western region of Bordj Bou Arreridj. The earthquake centred in the zone contained between the Bibans, Portes-de-Fer, Medjana and Mansoura. It caused a loss of at least 9 lives, injuring 11 and rendering several homeless; it destroyed or badly damaged about 250 local traditional housing units and colonial structures. The main shock, which was preceded by one foreshock, was followed by a series of aftershocks. It caused significant changes in the flows of many springs in the affected zone. The earthquake was associated with rockfalls in Djebel Mansoura. Detailed study of the macroseismic information collected from various sources available to us has led to a re-estimation of intensities at many sites. Maximum intensity has been re-evaluated at I_0 = VIII (MSK), allocated to Mansoura, douar M'Zita and its depending hamlets, Arbea, Mansoura-Kebira, Mansoura-Seghira and their immediate vicinities, and covers an area of about 9 km radius. The shock was felt as far as Ain M'Lila 180 km away. From the intensity data, an isoseismal map has been constructed and macroseismic epicentre located at 36.09°N, 4.48°E. The instrumental epicentre has been relocated, using the present ISC location procedure and readings from 33 seismological stations, at 35.9°N, 4.0°E. The surface-wave magnitude was determined, without station corrections, at 5.30 (± 0.04).

1. Introduction

On the 16th of April 1943, at 11 h 43 min 14 s (GMT), a destructive earthquake occurred in the eastern part of the Tell Atlas in the Bibans ranges. The epicentral area, which centred in Mansoura, is situated at 150 km southeast of the capital Alger. The main shock, which killed at least 9 people and injured 11, caused major damage in the zone containing Medjana, Portes-de-Fer and Mansoura. It destroyed about 250 local traditional housing units, slightly damaged European buildings. Radius of perceptibility was relatively small, the shaking was felt in the zone comprising El Esnam, Maillot, Bouira, El Adjiba, Akbou, Guelaa, Ighil Ali, El Kseur, Tixter, Bir Kasdali, Medjez, Cerez and Ain M'Lila.

The main shock, which occurred with one foreshock, was followed by a series of aftershocks, continuing until September 1943. The earthquake was associated with rockfalls in Djebel Mansoura and caused changes in flows of several springs in the region. We found no evidence of any sign of liquefaction or other ground deformation features in the affected zone. The main shock was recorded by most of the seismological stations operating at that time, up to Pasadena 92° away. The instrumental epicentre was relocated, using the present ISC relocation procedure and readings reported to the ISS, at 35.9°N, 4.0°E. Using the standard Prague formula, the surface-wave magnitude was computed, without station corrections, at 5.30 (± 0.04).

Compilation and critical analysis of the macroseismic data inferred from various contemporary documents relative to this earthquake have greatly contributed in the re-assessment of the amount of damage caused to humans, man-made structures and to the ground itself. These documents have also revealed the type of constructions that existed at that time and the state they were in. The building characteristics added to the macroseismic information collected have allowed us to re-evaluate intensities in many sites. Maximum intensity has been re-estimated at I_0 = VIII in the MSK intensity scale, allocated to Mansoura, douar M'Zita, Arbea, El Achir and their immediate vicinities, and covers an area of about 9 km radius. From the intensity data, an isoseismal map has been constructed and the macroseismic epicentre located slightly north of Mansoura, at 36.09°N, 4.48°E.

2. Sources of information

According to the seismic history of the region reported by Hée (1925, 1933, 1950), Rothé (1950, 1969), Grandjean (1954), Mezcua and Martinez (1983) and Benhallou (1985), this earthquake constitutes one of the most destructive seismic events that occurred in the Bibans ranges during the last two centuries. A broad search for contemporary documents was carried out in libraries and archives in order to collect macroseismic data relative to this event. The result of this search is a collection of contemporary newspapers and technical reports. It was supposed that the information relative to this earthquake would be abundant, particularly in the Algerian and French press, as for past destructive ones. This was not so; the information either in the press or in the technical reports were rather scarce and limited to large villages and douars. This lack of information is mainly due to the fact that the earthquake occurred during the Second World War which prevented detailed reports and thus study.

In the press, the most extensive account is given in «L'Echo D'Alger» (1943) which contains important data. The technical reports are limited to brief overviews of the earthquake effects by Rothé (1950) and Grandjean (1954). Rothé, quoting the press, the director of a school in Mansoura and a school teacher in Medjana as his sources, described briefly the effects of the earthquake. He located the macroseismic epicentre, between Dar Beida and Oued Chebba Valley, at 36.13°N, 4.58°E. Grandjean (1954), quoting Rothé (1950) and the press as his reference, summarized in few lines the impact of the earthquake. No isoseismal map of this earthquake was published.

In the recent catalogues, the instrumental epicentre assigned to this shock is: 36.1°N, 4.6°E (ISS, 1943) which is repeated by Karnik (1969), 35.5°N, 4°N (Gutenberg and Richter, 1965), 36.08°N, 4.55°E (Grandjean, 1959) which is repeated by Mezcua and Martinez (1983) who quoted the IPGA as his source. Maximum intensity was evaluated at IX (MS), (Grandjean, 1954; Karnik, 1969); IX (MM), (Khemici in EERI, 1983) and IX (MSK), (Mezcua, 1983). Magnitude was calculated at: M = 5.0 (Rothé, 1950), M_S = 6.60 (PAS), M_S = 5.2 (Karnik, 1969), M = 4.0 (Khemici in EERI, 1983) and m_b = 5.0 (Mezcua and Martinez, 1983).

3. Geographical aspects of the region

The epicentral zone of this earthquake lies between the Bibans massif and the Hodna chain. Under the meridian of Alger and Medea, the median chain of the Tell Atlas is divided into two branches: the Bibans and the Hodna. The Bibans chain is limited in the east by the Babor ranges and extends up to the north of Setif. It constitutes a quasi-continuous line that runs through Berrouaghia, north of Aumale, and which is clearly shaped by the defile of

Portes-de-Fer. The chain spreads out in the country of Beni Abbes and raises to 1164 m at Guelaa of El Mokrani, then forms the Guergour massif (1613 m) and the Djebel Anini (1598 m). It is one of the orographic lines the most distinctly drawn in the whole of the Tell Atlas. The soil of the region is very poor, it is covered mainly with bushes, few oak trees on the schists and Alep pines on the limestones. East of Portes-de-Fer, the Kabyle tribes, very densely populated, notably those of Guergour, live on the north flank of the chain, whereas the southern side is occupied by sparsely distributed douars and hamlets. Most of the native people houses were very old and in bad state. Their walls consisted of mud-straw or stones with great thickness of lime or clay mortar joints. The colonial constructions were relatively better built with ordinary masonry or stones with cement mortar joints. Roofs were heavy, the ends of the joists of wood which simply rest or inserted only few centimetres into the bearing walls. A slight outward movement of the wall is sufficient to allow joists to loose their support and overturn the other supporting wall. It is of importance to mention that most of these houses suffered considerable decay through ageing, heavy rain, neglect, improper repairs and earthquakes. In other words, the building stock exposed to the shaking was characterized by its low and variable strength, and its extremely high vulnerability.

4. Damage and casualty distributions

The Mansoura earthquake of 16 April 1943 occurred with one foreshock 10 min before the main shock and was followed by a series of aftershocks. It centred at about 150 km southeast of the capital Alger. Detailed analysis of the macroseismic information collected from contemporary sources relative to this earthquake has revealed that maximum damage was observed in the douar M'Zita (city of Medjana) and its surrounding hamlets.

In the douar M'Zita the main shock caused the loss of at least 3 lives, injuring 9 and making around 900 homeless; it seriously damaged about 150 native people housing units and ruined 30. In the village Dar Beida, located on a rocky crest, the earthquake killed 3 people and injured several others. Details were not communicated. The forest house of Arbea-Arboul was significantly damaged. The damage consisted of deep and large cracks, and collapse of sections of many walls. In Mansoura the shaking was strong enough to dislocate partition walls and cause serious fissures in the European buildings. The northern tower of the gendarmerie barracks had seen its top overthrown. It also caused major damage to at least 21 local traditional housing units. Two muleteers were injured by the collapse of a wall. The main shock triggered significant rockfalls in Djebel Mansoura. In Mansoura-Kebira the earthquake partly destroyed 34 native people housing units, produced important fissures in the school buildings and caused fall of chimneys. In Mansoura-Seghira the shock damaged at least 10 local traditional houses of which no details were communicated. In Medjana and El Achir damage consisted of the collapse of few traditional houses. In Bordj Bou Arreridj, it was reported that only slight damage was caused to structures, but no details were given. In Oued Chebba Valley the shaking was particularly violent, all along the Alger-Constantine railway, between the kilometric stones 214 and 216. At the kilometric stone 214.700, the roadmen house was razed to the ground. The small recently built train station, at the stone 216.500, had its walls dislocated. Four bridges at the kilometric stones of 214, 216 and 217.500 had their abutments cracked and parapets overturned. The rail traffic was interrupted for six hours so the railway can be repaired. In the village Ouled Aicha, the flow of the spring decreased substantially. In the hamlets of El Bour, M'Cil-El-Houd, Gasba, Taourirt, Haouch-El-Farroudj and El Merdja (Douar of M'Zita), many springs dried up after the shaking. It was reported that the shaking was felt in El Esnam, Maillot, Bouira, El Adjiba, Akbou, Guelaa, Ighil Ali, El Kseur, Tixter, Bir Kasdali, Medjez, Cerez and Ain M'Lila but details were not communicated. It is of interest to mention that the behavior of people was not reported in any contemporary source.

5. Intensity re-evaluation

All the macroseismic data provided by the various contemporary documents were used, with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale, to re-evaluate intensities. After a critical analysis of these data, maximum intensity has been re-estimated at I_0 = VIII (MSK), allocated to Douar M'Zita and its hamlets, Mansoura, Arbea-Arboul, Mansoura-Kebira, Mansoura-Seghira, Oued Chebba Valley (36.07°N, 4.55°E) and their immediate surroundings, and covers an area of about 9 km radius. This intensity was assigned to the sites where maximum damage as destruction of houses and loss of life were observed. Intensity VII was attributed to Medjana, El Achir and Ouled Aicha. Intensity VI was assigned to Bordj Bou Arreridj. Intensity III was attributed to Ain M'Lila, Akbou, Bir Kasdali, Bouira, Cerez, El Adjiba, El Esnam, El Kseur, Guelaa, Ighil Ali, Maillot, Medjez and Tixter. Intensities VI and VII were allocated with a rigid interpretation of the MSK intensity scale (Medvedev *et al.*, 1981). Intensity III was assigned solely on felt effects and lack of damage to poor-quality structures.

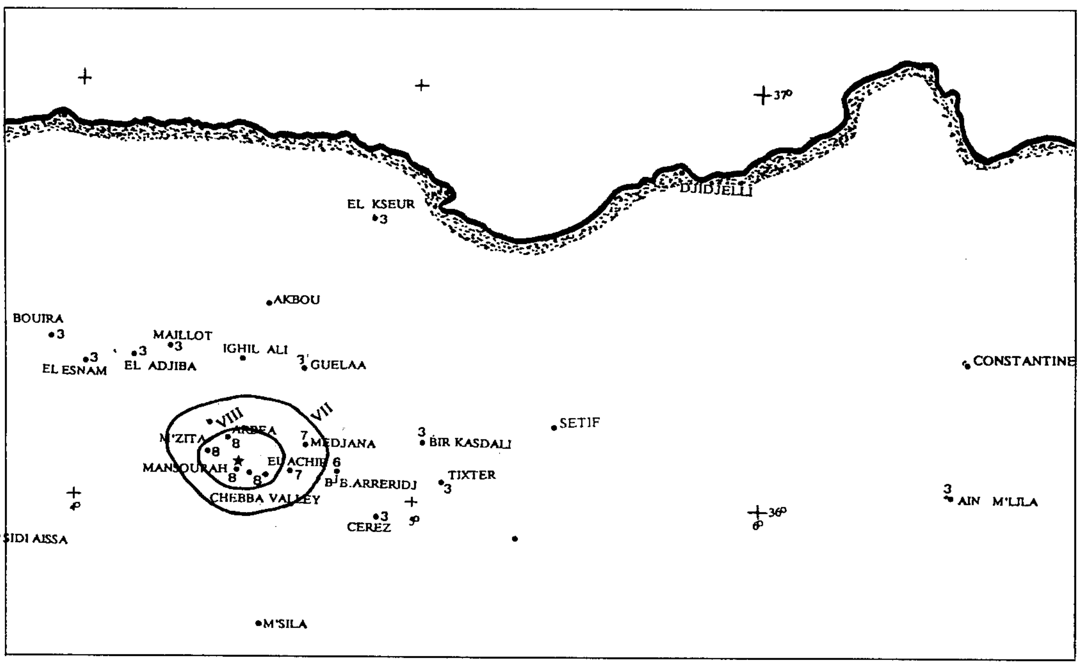

Fig. 1. Isoseismal map (in terms of MSK scale) of the main shock of the 16 April 1943 earthquake. The star shows the macroseismic epicentre of the main shock.

From the intensity data, an isoseismal map of the Mansoura 16 April 1943 earthquake has been drawn and is shown in fig. 1 on which were plotted the re-estimated intensities.

6. Magnitude determination

The surface-wave magnitude of the main shock was computed from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from two seismological stations located at distances between 12° and 22°, and a preliminary epicentre (macroseismic) at 36.09°N, 4.48°E. The data and the results are shown in Benouar (1993). The mean period is 12 s and the derived value of M_S, without station corrections, is 5.30 (± 0.04).

7. Teleseismic relocation

Fourty four seismological stations reported the main shock to the International Seismological Summary (ISS), the closest being Almeria (Spain). The earthquake was recorded through Europe as far as Aberdeen and Yalta, in Helwan (Egypt) which is on the same continent, in Ksara (Lebanon) in the Middle East and in the U.S.A. as far as Pasadena 92° away. Stations with large residuals have been weighed small or left out of analysis. With a trial origin taken at 36.100°N, 4.600°E and data from 36 stations, we find:

1943 April 16
11 h 43 min 14 s (± 3.4)
35.9°N (± 0.20), 4.0°E (± 0.16)
Depth = 4 km.

This position agrees with the macroseismic epicentre with errors of about 21 km in latitude and 53 in longitude.

8. Foreshocks and aftershocks

The main shock was preceded by one foreshock, on 16 April 1943 at 11 h 32 min 20 s (GMT), which was recorded by Alger-University station. We found no report of whether it was felt in the affected region or not. In the other hand, the earthquake was followed by at least 42 aftershocks, continuing until 3 September 1943. These aftershocks had seriously undermined the spirits of the population who refused to join back their fragile homes and remained under rough shelters for more than a week.

The largest aftershocks occurred on 7 June 1943 at 10 h 38 min and on 10 June at 7 h 48 min. These largest aftershocks were both strong enough to cause collapse of walls, fall of plaster in Mansoura (VI MSK) and seriously felt in Bordj Bou Arreridj, Ighil Ali, Guelaa and El Adjiba.

9. Discussion

According to the seismic history of the region reported by Hée (1925, 1933), Rothé (1950, 1969), Benhallou and Roussell (1971) and Benhallou (1985), the Mansoura 16 April 1943 earthquake is one of the largest felt and recorded seismic events in the region. The western part of the Bibans chain experienced a destructive earthquake that occurred on 24 June 1910 and caused heavy damage to the northwestern region of Aumale. This earthquake shows the potential for a higher degree of inhomogeneity of seismicity and the consequences of this in the evaluation of seismic hazard in Algeria.

For a better estimation of the strength of the ground shaking, a comprehensive investigation was carried out to learn about the type of constructions that existed during that period and the state they were in, in order to add the macroseismic information collected and thus re-assess intensities with an appreciable degree of reliability. The reconstruction of the macroseismic field of this event has shown that, as in past destructive earthquakes in Algeria, structures built with adobe, stone or unreinforced masonry bearing walls sustained either total destruction or heavy damage. The damage was particularly widespread in sites close to the epicentre.

However, in order to study earthquakes of the past critically, it is important to take into account the political, socio-economic and demographic conditions, cultural and religious background and the building stock characteristics of the period concerned. The fact that the earthquake occurred during the Second World War period, which was characterized by lack of food and unemployement, made the shock fall into a second place. In reality, the earthquake added little to the every day misery that people, particularly native Algerians, were living. It is certain that in the absence of the war, more consideration would have been given to the earthquake and its effects magnified in the documents. According to the extent of damage reported, we believe that the casualty toll among the native people was much higher but details were not communicated. It is true that the war situation prevented the press and the scientists to carry out their works which made the information in the contemporary sources scarce and limited to serious damage in villages and large douars around the epicentre. We found no account relative to the behavior of the population which is very important in the re-estimation of certain intensities. Numerous scattered small douars and hamlets within the radius of perceptibility, which could have enriched the data, were not mentioned. We believe that the exact casualty toll may never be known as many victims, buried immediately to conform the Islamic law, and their deaths were either not reported to the French administration in order that the family will continue to receive the food wartime rations or simply left out by the administration. It is of great interest that, during wartimes and colonization periods in Algeria and elsewhere, macroseismic data be inferred from contemporary military sources which, unfortunately, are not available to us today; these accounts because of their official character contain ample and more reliable information.

Summarizing the results, we obtain the following final data for the Mansoura 16 April 1943 earthquake: origin time: 11 h 43 min 14 s (GMT); instrumental epicentre: 35.9°N, 4.0°E; focal depth: 4 km; macroseismic epicentre: 36.09°N, 4.48°E; maximum intensity I_0 = VIII (MSK); magnitude: $M_S = 5.30\ (\pm\ 0.04)$.

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The Berhoum earthquake of 12 February 1946

Abstract

This research examines one of the largest earthquakes in the Hodna in this century. The Hodna earthquake of 12 February 1946, occurred at 2 h 43 min 24 s and was the largest recorded event in the region since 1900. It caused heavy damage to a small area at the junction of four districts (Maadid, Rirha, Barika and M'sila). Most damage was reported to be observed at the douars Ouled Addi Guebala, Berhoum and Ouitlem. The macroseismic epicentre has been located between these three douars, but much more toward Berhoum. The earthquake had triggered a certain number of rockfall and landslides. The main shock caused the loss of at least 277 lives, injured about 118 and rendering approximately 7500 people homeless; it also destroyed or heavily damaged about 1000 housing units in 10 douars. This earthquake also caused the deaths of 576 sheep, and goats, 23 horses, mules and cattle and 14 donkeys. After careful analysis of the macroseismic data extracted from different sources, we re-estimated the maximum intensity at I_0 = VIII in the MSK scale and the area at around 11 km radius. The main shock was felt, in a relatively small area, as far north as Bougie, west as Boghari, south as Tolga and east as Ain M'lila, about 70000 square km. As a result of the analysis of the damage caused to human, man-made structures and on the ground itself, an isoseismal map has been drawn. The earthquake was widely recorded. The macroseismic epicentre has been located between Berhoum and Ouled Addi Guebala, at 35.70°N, 5.00°E. The surface-wave magnitude was calculated, using the teleseismic data, at 5.55 (± 0.17). We learned from the archives that the damage was due not only to earthquakes, but also to heavy rain that poured days before and after the shaking. The reconstruction of the macroseismic data field of each destructive earthquake is of great importance in the evaluation of seismic hazard, particularly in regions where large events are infrequent.

1. Introduction

On the 12th of February 1946, at 2 h 43 min 24 s (GMT), the Hodna plain was hard hit by a devastating earthquake. The main shock was recorded by almost all the European seismological stations and up to Weston, Saint-Louis and Pasadena (U.S.A.). According to the historical seismicity of that region of Algeria, it was by no means an unprecedented earthquake. The epicentral zone, located in the Hodna plains, has experienced several devastating earthquakes in the past (Chesneau, 1892; Rothé, 1950; Press Reports). Certainly, a complete study of these historical events will provide valuable information for seismic hazard evaluation in the restricted region and in the whole of Northern Algeria, since many of the geographical and human characteristics found in the Hodna plain are very common in other seismic zones of the country. Consequently, a detailed study of the affected area is pertinent both to eastern and the whole seismic Algeria. The Hodna earthquake of 12 February 1946 occurred in the southern flank of the Hodna ranges (fig. 1).

The shaking was felt, in a relatively small area of about 150 km radius, as far

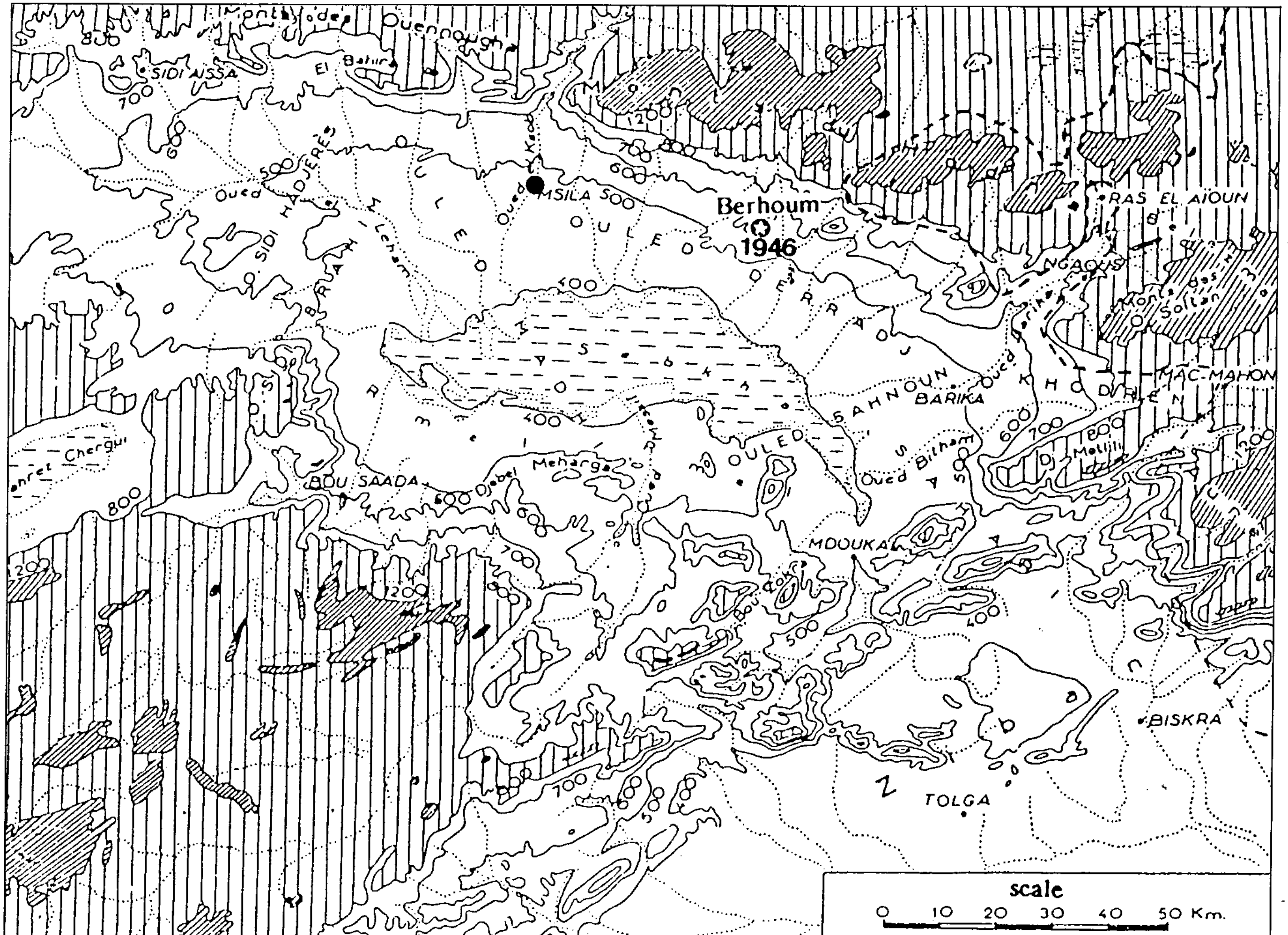

Fig. 1. Map of the Hodna plain and its surrounding mountains. The star shows the macroseismic epicentre of the main shock of the 12 February 1946 earthquake.

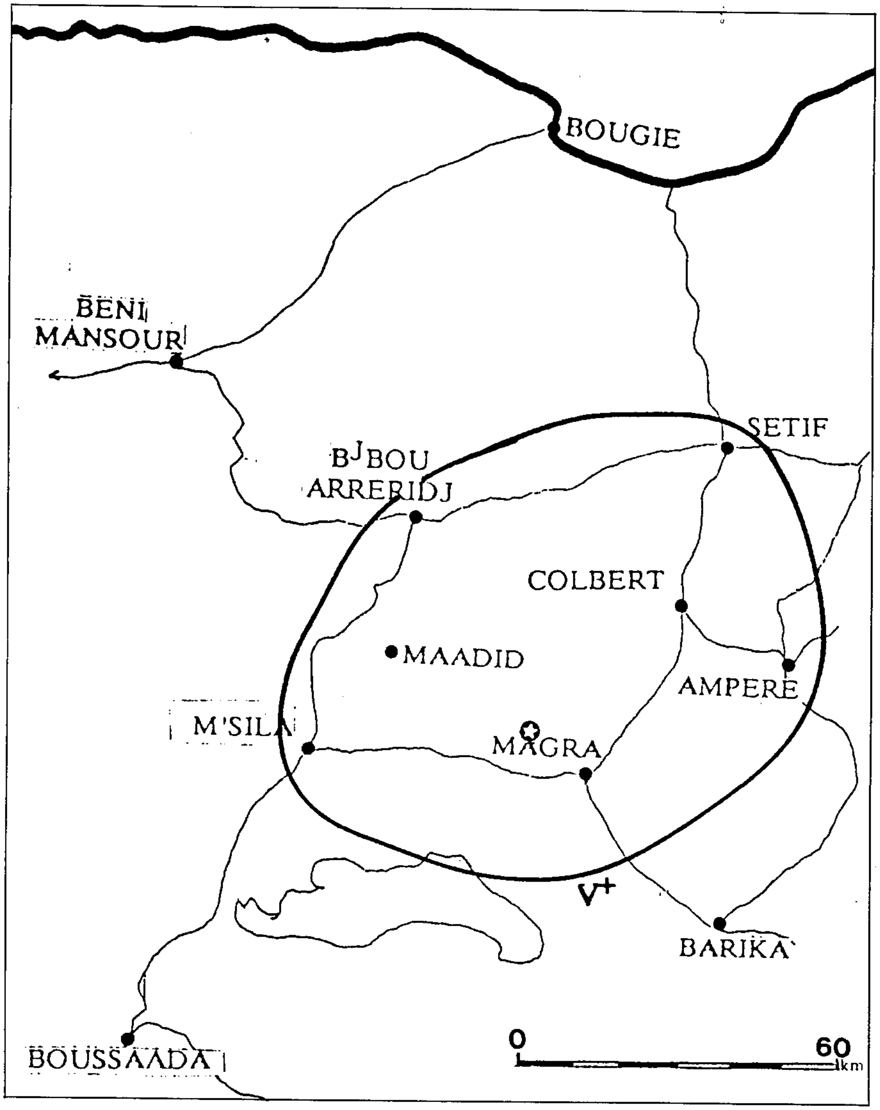

Fig. 2. Map of the most affected region of the 12 February 1946 earthquake showing the approximate area of intensity V^+ (MSK). The star shows the macroseismic epicentre of the main shock.

west as Boghari, east as Ain M'lila, north as Bougie and south as Tolga with intensity III^+ in the MSK scale. Maximum intensity reached VIII in the MSK and covers an area about 11 km radius. The main shock, which lasted several seconds, was strongly felt in the south-west sector of the Constantine region, delimited by the localities of Barika, M'sila, Maadid, Bordj Bou Arreridj and Setif, where significant to slight damage was observed with intensity V^+ (fig. 2). It is reported that 277 people were killed, 118 injured and approximately 1000 housing units in 10 douars were destroyed or badly damaged rendering about 7500 people homeless (Press, 1946). The livestock, surprised under the gourbis which they usually share with humans, suffered major losses. It is reported that 576 sheep, and goats, 23 horses, mules and cattle and 14 donkeys were killed.

It is very important to mention the unusually heavy rain which poured onto the stricken region for days before the earthquake.

The area worst hit, where maximum damage was observed, encompasses douars in 4 districts (Communes mixtes) of M'sila, Maadid, Barika and Rirha, and is about 11 km radius. All these douars are situated in the surroundings of the meridional flank or on the crestline of the Hodna mountains (Djebel Nechar 1858 m) and Djebel Agar (1746 m). The surface geology of the region has been studied in details by Savornin (1920). The time of occurrence (the majority of the people were caught asleep), the low resistance of the buildings to earthquakes and the torrential rain that struck the region were the main cause of the high casualty rate and the destruction of so many dwellings.

According to different sources, and particularly to Rothé (1950) and Grandjean (1954), the earthquake occurred without any foreshock and was not followed by any aftershock. It was associated with important rockfall and landslides which obstructed many roads and rendered the relief late and difficult. The relief had to be organized on muleback since the douars were at a long distance from any road suitable for motor vehicles. The surface-wave magnitude was recalculated, without station corrections, at 5.55 (± 0.17).

2. Sources of information

In order to reconstruct this earthquake with an appreciable degree of reliability, a comprehensive search was made in various

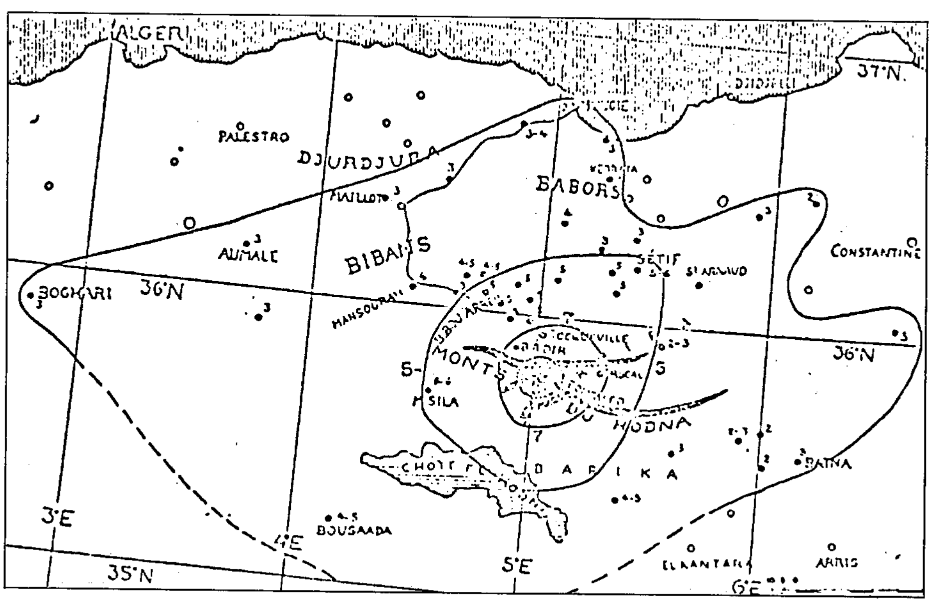

Fig. 3. Isoseismal map (MS scale) of the main shock of the 12 February 1946 earthquake, after Rothé (1950).

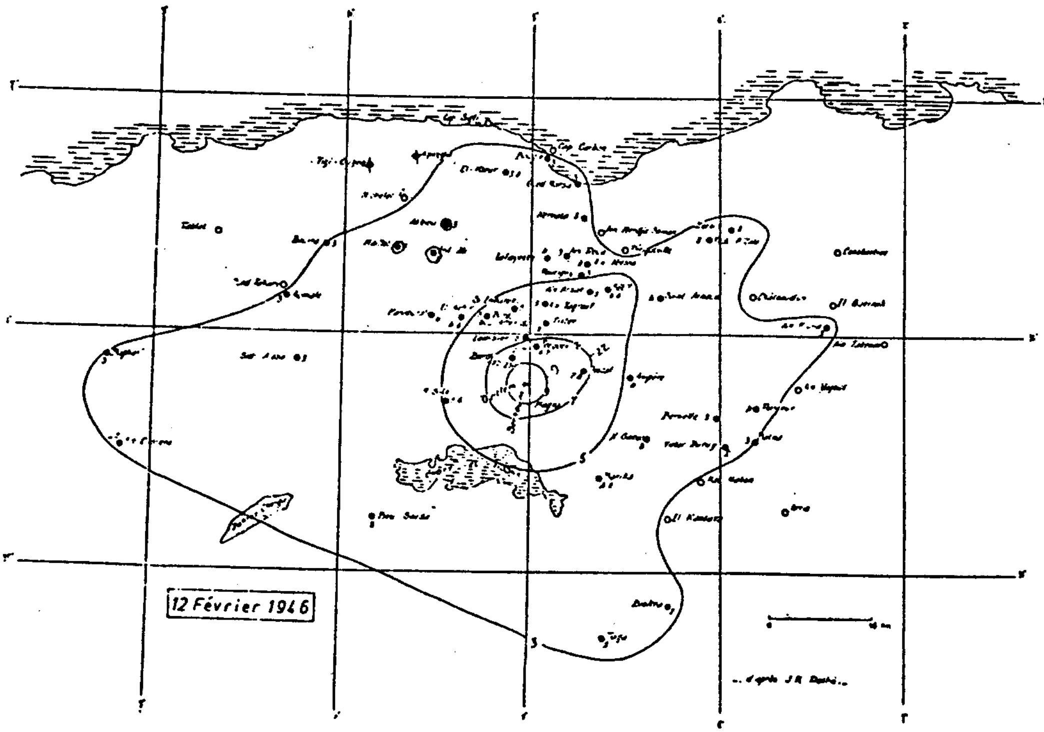

Fig. 4. Isoseismal map (MS scale) of the main shock of the 12 February 1946 earthquake, after Grandjean (1954).

libraries and archives. The macroseismic data, provided by the sources available to us, have considerably improved our knowledge of its effects and contributed greatly to its reconstruction. This event was widely reported in the International, and particularly the Algerian, press, but despite the importance of this destructive earthquake for the Hodna region, and also for the whole of Northern Algeria, only Rothé (1950) has studied it and published an isoseismal map (fig. 3). Grandjean (1954) briefly summarized the event and, using Rothé as source, published an isoseismal map (fig. 4). Other authors have assigned maximum intensity, but without quoting their sources, that is at I_0 = VIII (MM), (Ambraseys, 1981a); VIII (MS), (Rothé, 1950); IX (MM), (Khemici, 1981 in EERI, 1983); IX (MS), (Grandjean, 1959); VI (MM), (Munuera, 1963) and VIII (MM), (IMPGA, 1937). The Hodna earthquake was recorded by most of the seismological stations operating at that time. Instrumental epicentres were calculated at 35.7°N, 4.8°E (ISS); 35.750°N, 5.000°E (USCGS); 36.00°N, 5.00°E (GUTE). Macroseismic epicentre was located at 35.800°N, 5.000°E (IMPGA); 35.790°N, 5.050°E (Ambraseys, 1981a); 35.750°N, 4.95°E (Rothé, 1950); 35.8°N, 4.8°E (Munuera, 1963). Various Agencies and authors have also calculated the magnitude of the event at M_S = 5.60, m_b = 6.20 (Ambraseys, 1981a); M_S = 6.0 (Gutenberg and Richter, 1965); M = 5.6 (Rothé, 1950; Khemici, 1981); m_b = 5.4 (Munuera, 1963); MLH = 5.7, MLV = 5.6

(Vanek and Stelzner, 1946, 1960) and M = 5.6 (BCIS).

In the following a summary of the analysis of these documents and the resultant damage of the event is presented.

3. Geographical aspects of the epicentral region

The epicentral zone lies in the Hodna plain, which is about 200 km southeast of the capital, Alger. The affected region is located on the southern flank of the anticlinal axis of the Hodna mountains (fig. 1). The history of the region, including the evolution of the housing and the way of life of the people, is summarized in Melouza earthquake in this volume.

4. Damage and casualty distributions

All macroseismic data extracted from the contemporary documents related to this earthquake are used in its full reconstruction. The information collected has increased our knowledge about the effects of this event on humans, man-made structures, livestock, and on the ground itself. For this goal, a comprehensive search into historical sources and their careful analysis has been carried out. The various documents available to us mention that the worst affected zone was the region located at the junction point of the districts (Communes mixtes) of Maadid, M'sila, Barika and Rirha. The time of occurrence (the majority of the people and all the livestock being asleep), the low resistance of the buildings to earthquakes and the torrential rain that occurred in the region were the main causes of the high casualty rate and the destruction of so many buildings.

The douar Ouled Addi Guebala, district (Commune mixte) of M'sila, is a small agglomeration; located at the piedmont of the Hodna ranges at about 45 km east of M'sila, composed of adobe and drystone constructions, was severely affected. 40 native Algerians were reported killed in this douar and 36 injured, in the douars of Ouled Guesmia and Ouled Ouelha, of which one third were children. The earthquake destroyed or badly damaged 176 housing units rendering at least 1000 homeless. A major part of the livestock was decimated. This douar was not the worst hit, but it is located almost at the centre of the affected area, with the douars of Ouitlem and Taglait in the north, the douar of Berhoum in the south and in the east the douar of Guesmia. At the douar Ouitlem, as at Ouled Addi Guebala, 22 native Algerians were reported killed and the number of injured, which was certainly high, was not reported. Photographs taken shortly after the earthquake show the scope of the disaster. In the district of M'sila, 539 housing units were completely destroyed. In the district of Maadid and at the douar Maadid 10 people (native Algerians) were killed, 69 at the douar Taglait and 30 injured. The earthquake caused the destruction of at least 177 housing units, rendering about 1200 people homeless. At Bordj R'dir, a small douar, numerous houses (gourbis) were destroyed or badly damaged. Houses built of rammed earth (pise) resisted the shaking better, but drystone ones collapsed. At the district of Barika 113 people were killed and 41 injured at the douar of Berhoum, where most damage was reported. 10 other people were killed at the douar of Magra. In the whole district of Barika, 127 housing units were totally destroyed and 139 partly damaged, making about 1800 people homeless. At the district of Rirha, in the douar of Ouled Tebben, 13 people were reported killed and 11 injured. The shaking caused the total destruction of 38 dwellings rendering about 250 people homeless. 35 km northeast of Berhoum, at the village of Pascal, the collapse of many houses and the fall of chimneys was observed. At Setif, located about 70 km northeast of Berhoum, the shaking was strongly felt. The alarm clock of a garage stopped at 2 h 44 min, which corresponds to the time of the main shock. The seismic movement was in the north-south direction. The Press «Le Monde» (1946) reported that 153 were killed and 40 injured in the County (Borough) of Setif, 123 killed and 33 injured in the County of Batna but this information could not be confirmed from other sources. Massive rockfall and landslides obstructed the route between Setif and Magra. The national road 28 was closed to traffic at the gorges of Soubella following the successive landslides caused by the shaking, or possibly by the heavy rain. The route from Colbert to Barika was also blocked by landslides and rockfalls. At Tocqueville, 35 km north of Berhoum, many ceilings were reported cracked. The shaking was strongly felt at Bordj Bou Arreridj, 55 km north-west of Berhoum, but did not cause any damage or casualties. It was also seriously felt by many people at Biskra, Boussaada, Beni Ilman and Melouza, but no damage or casualties were reported. In the whole south-west Constantine region, over an axis of about 100 km, all the villages, and particularly the douars, were more or less affected by the earthquake, but it was the douar of Berhoum and its close surroundings that suffered most. After much careful analysis of the macroseismic data provided by the contemporary sources, we have located the macroseismic epicentre between Berhoum, Ouitlem and Ouled Addi Guebala at 35.70°N, 5.00°E. Old people of the region suggest that the epicentre was at the douar of Ouled Tebben close to the hot springs.

5. Intensity re-evaluation

All information, extracted from the different historical sources available to us, has been used in the re-estimation of intensities with, as reference, the Medvedev-Sponheuer-Karnik (1981) scale.

According to the history of Algeria and its constructions, the typical house in the Hodna, as in many other parts of the country, had shown a very low strength and an extremely high vulnerability to earthquakes and to heavy rain. Thus, the degree of damage to this type of housing is generally an indication of the weakness of the structure, caused by ageing, wars, earthquakes and, particularly, by lack of proper repair, rather than the strength of ground shaking. It is very important to take into account the heavy downpour of rain that the Hodna region experienced for days before the earthquake, and which certainly affected the old «toub» dwellings.

As the result of the weakness of these constructions, maximum intensity in any destructive earthquake seems to be the same. That is, at intensity IX-X (MSK scale), most of the houses are destroyed and any douar would thus look equally, but no more devastated at higher intensities. For this reason, it is unlikely that intensity IX was reached since many houses (type A as defined by the MSK scale) did not experience total destruction. After a careful analysis of the different phenomena that have contributed to the damage besides the earthquake, maximum intensity was re-estimated at VIII and was attributed to the douars of Ouled Addi Guebala, Guesmia, Ouitlem, Berhoum and Ouled Tebben. Broadly, it was assigned to sites where many constructions of type A, as defined by the MSK scale, were destroyed or heavily damaged and loss of life was reported. Intensity VII was assigned to Pascal, Tocqueville, Maadid, Ouled Djerad, Ouled Mansour, Magra and Bordj R'dir where the douars suffered such serious damage as deep cracks, fall of walls and also where the population was frightened and ran outdoors, but with low loss of life. Intensity V-VI was allocated to Setif, Bordj Bou Arreridj, M'sila, Colbert, Ampere, Lavoisier and Lecourbe where such damage as fine cracks in plaster, small cracks in walls and fall of plaster was observed in the constructions of type A as defined in the MSK scale. Intensity III-IV was attributed to Boghari, Bouira, Aumale, El Kseur, Bougie, Kherrata, Ain Abessa, Fedj M'zala, Ain M'lila, Batna, Biskra, Tolga, Boussaada and Ain Oussera according to Rothé (1950) who

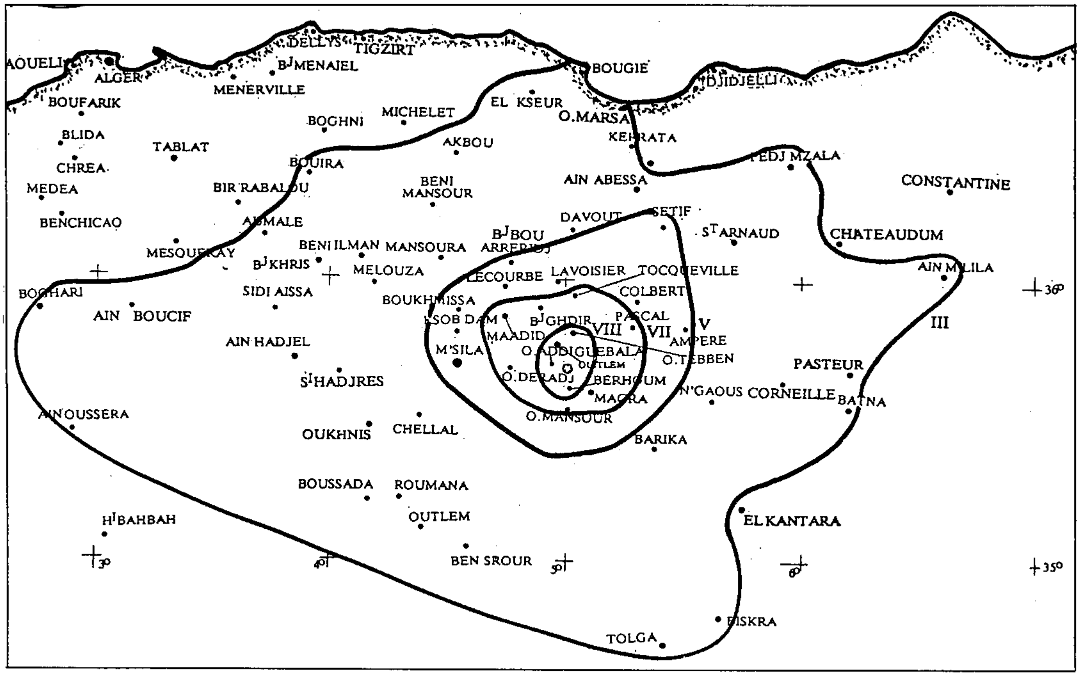

Fig. 5. Isoseismal map (MSK scale) of the main shock of the 12 February 1946 earthquake. The star shows the macroseismic epicentre of the main shock.

did not mention his source. The same Rothé information was used later by Grandjean (1954) and Benhallou (1985). We found no report, in any contemporary source available to us, about the felt limits of the earthquake in the region.

As a result of the analysis of the different effects of the earthquake on humans, constructions, and on the ground itself, an isoseismal map has been drawn and is shown in fig. 5.

6. Foreshocks and aftershocks

According to the sources available to us, the earthquake was not preceded by any foreshock and was not also followed by any aftershock. It is unusual that a shock of this size is not followed by any aftershocks.

7. Magnitude determination

Using the surface-wave amplitude and period readings of the main shock, from 8 seismograph stations at epicentral distances between 6° and 22°, the surface-wave magnitude was calculated from the standard Prague formula (Vanek *et al.*, 1962), without station corrections and a macroseismic epicentre at 35.70°N, 5.00°E, M_S = 5.55 (± 0.17), confirming that it was a moderate earthquake. The details of the data and the result are given in Benouar (1993).

8. Teleseismic relocation

Readings were taken from 66 seismological stations which reported the earthquake to the International Seismological Summary (ISS), the closest being Alicante (Spain). The event was recorded throughout Europe as far as Sverdlosk 43° away. It was also reported by Helwan (Egypt), a station on the same continent, Ksara (Lebanon) in the Middle East, Bombay (India) in Asia and by many U.S stations up to Pasadena 93° away. Most of these reporting stations were in Europe, so they were all to the north, resulting in a poor azimuthal distribution of stations around the epicentre. With the macroseismic epicentre (35.70°N, 5.00°E) taken as trial origin, the solution, using the present location procedure of the ISC gives:

1946 February 12
2 h 43 min 25 s (35.7°N 4.82°E),
Depth = 18 km.

This position agrees with the macroseismic epicentre with errors of about 13 km in latitude and 7 km in longitude. Stations with large residuals have been weighted small or left out of the analysis.

9. Discussion

The Hodna earthquake of 12 February 1946, by its size, number of casualties and damage, is the largest felt and recorded event in the Hodna region since the beginning of this century. Although it is practically impossible at this stage to assess in detail the effects of this earthquake at each site of the felt region, from the retrieved macroseismic data, the importance of this event is shown in terms of seismic hazard evaluation for the region, and even for the whole Algeria. Since documents, generally, reflect only serious damage, they are only found in the region close to the epicentre. We remarked that felt reports, which correspond to lower intensities, as well as negatives ones, are given only for important towns, villages or douars. Many intermediate sites within the felt region were not mentioned at all.

As a result of the analysis of the macroseismic data extracted from sources available to us, maximum intensity VIII (MSK) was assigned to the douar of Berhoum (northern part) and covers an area of about 11 km radius. From the isoseismal map (fig. 5), we note that the general axis of the macroseismic zone, which is in the W-E direction, is elongated along the southern flank of the Hodna. We also see that the seismic waves were more attenuated toward the east than the west, where they propagated as far as Boghari.

It caused sufficient damage and casualties to be recorded in a large number of contemporary documents. The high fatalities are mainly due to the time of occurrence (people were asleep) and low quality of constructions already seriously affected by the heavy rain that poured on the region for days before the earthquake. The most extensive account is given in the «Echo d'Alger» which relates in detail the historical context of the earthquake. For historical events, press reports are generally rich in details and are an indispensable aid in establishing chronology. These reports should be, of course, carefully considered in the framework of the political, socio-economical, cultural and religious background, demographic conditions and building characteristics of the period concerned (Ambraseys, 1983). This disaster gave a political opportunity to the French government to show to the native Algerians that France had not forgotten their good service during World War II and that it was very much concerned, not only about the disaster, but about the whole miserable socio-economical condition of the region, which after the earthquake became insufferable. Five years of complete drought, the Second World War and then a period of torrential rain, followed by the earthquake, completed the decimation of the region. These phenomena brought the native Algerians to starvation, unemployment and total poverty by the loss of their homes, cattle and scarce agriculture. Many young people, before the earthquake, migrated to large cities and even to France. The social situation explains why this particular earthquake had been, exceptionally, widely reported in the Algerian and French newspapers. It had also gained an unusual distinction: a visit of the French Interior Minister, who came to praise the native Algerian soldiers who fought beside France in World War Two and to promise to solve their social problems. Galas and charities were organized, which attracted the particular attention of the public in both Algeria and France.

We believe that the exact toll of casualties may never be known, as many victims were buried immediately after the earthquake to conform to the Islamic law, or simply voluntarily omitted by the administrative authorities; this subject has been discussed in section 1. Chapter I. We found different casualty rates, as Rothé (1950) states 264 lives lost and 112 injured, but the Press (1946) mention 277 killed and 118 injured. The toll must be higher than was declared, since the population was caught asleep and the majority of them were trapped under the rubble of their houses.

Although the damage, as reported by different sources, was due to the earthquake, in the re-estimation of intensities we have taken into account the type of constructions that were exposed and the heavy rain which occurred in the region.

It is certain that, in the Hodna region, a precise relocation of the epicentres will be of prime importance in revealing deep tectonic features and assessing the seismic hazard in the region.

Summarizing the results, we obtain the following data for the 12 February 1946 earthquake: origin time 2 h 43 min 24 s; relocated instrumental epicentre at 35.7°N, 4.82°E (Ambraseys, 1981a); macroseismic epicentre at 35.70°N, 5.00°E; focal depth about 8 km; maximum intensity I_0 = VIII (MSK); magnitude $M_S = 5.55$ (± 0.17).

ANNALI DI GEOFISICA, VOL. XXXVII, N. 4, July 1994

The Constantine earthquake of 6 August 1947

Abstract
This research considers one of the most destructive earthquakes that occurred in Constantine in this century. The Constantine earthquake of 6 August 1947 occurred at 9 h 46 min 38 s (GMT); it is one of the most devastating earthquakes of the region. The main shock, which lasted about 8 s, caused a loss of at least 3 lives, injuring several and making numerous homeless; it destroyed many housing units and farms in the epicentral area. It was preceded by two foreshocks and followed by a long sequence of aftershocks. After a careful analysis of the macroseismic data extracted from the sources available to us, maximum intensity is re-estimated at I_0 = VIII (MSK) and covers Oued Hamimine and its surroundings, an area of about 7 km radius. The main shock was felt in a relatively small area of about 140 km long and 110 km wide. This earthquake is classified as moderate and shallow event with a focal depth of about 10 km. The macroseismic epicentre was located at Oued Hamimine northwest of Khroub at 36.314°N, 6.680°E. The surface-wave magnitude of the main shock was calculated, without station corrections, at 5.00 (± 0.29). Analysis and detailed study of destructive earthquakes are fundamental for the assessment of the seismic hazard and risk in regions where the frequency of large events is low.

1. Introduction

On Wednesday 6th of August 1947, a strong earthquake caused widespread destruction at the town of Constantine and its surrounding region. The epicentral area is located at about 330 km east from the capital Alger. It has been 39 years that the Old-Rock (name given to Constantine because it is built on a rock) had not lived a similar nightmare. On 4 August 1908, in fact, Constantine region was terrified by a much stronger earthquake. The same phenomena was recorded but with more important consequences. The population had known the same anguish, and had fled from their homes looking for a safer shelter in the public gardens. This 1947 earthquake shows that Constantine region is really a target of cyclic convulsions. By its size and the damage caused to the region, the 1947 Constantine earthquake constitutes one of the most major recorded event in the region since 1908.

The 1947 earthquake, that occurred at 9 h 46 min 38 s (GMT) on 6 August in Constantine, affected a relatively densely populated area of about 80000 inhabitants in about 3000 square km. The shaking was felt, in a relatively small area of about 65 km radius, as far east as Medjez Amar, west as Fedj M'zala, south as Ain Fakroun and north as the coast with intensity III$^+$ in the MSK scale. The main shock caused the loss of at least 3 lives, injuring several other and making numerous homeless; it destroyed several houses in the epicentral area and particularly at Oued Hamimine (district of Khroub). Although most of the constructions in Constantine and surrounding villages sustained damage as cracks in walls, fall of chimneys and fall of plaster, the modern buildings built of freestone or reinforced concrete did not suffer any damage. The duration of the main shock was 24 s according to the record of the IMPGA (Alger) and was, as reported in Constantine, between 6 and 8 s. The culminating time of the shaking was around the 4th second. The shaking was strongly felt in the southeast sector of Constantine where significant to slight damage was observed with intensity V^+. The main shock was preceded by two slight foreshocks and followed by a long sequence of aftershocks which accentuated the damage. The succession of the aftershocks caused a general panic at Constantine: about 10000 inhabitants fled the city to camp in the gardens or left for the countryside.

We found no information of any ground features produced by the shaking. However, it was reported that the water flow and temperature had been disturbed in the region.

Detailed analysis of this earthquake provides a fundamental mean for the mitigation of future catastrophes by suggesting ways of improving local constructions procedures, materials, layout and location of new urban and rural sites. A re-evaluation of the effects of this event in this restricted area is therefore pertinent to Eastern Algeria and to the whole of the country, in terms of seismic hazard and risk evaluations.

2. Sources of information

To reconstruct the macroseismic data field of this earthquake with a certain reliability, a comprehensive search was made in various libraries and archive centres. The macroseismic data extracted, from various sources available to us, have improved substantially our knowledge of the effects of this earthquake on the region and contributed greatly to its reconstruction. Because it affected the third largest city in Algeria, this earthquake was widely reported in the Algerian and International press. Although the press is destinated to the general public its style of reporting, which is generally accompanied with photographs and interviews, makes it a valuable source. Some of these documents contain very detailed information as names of villages, douars, houses, farms, even streets where damage was particularly observed. The most extensive account of the 1947 Constantine earthquake is given in «La Dépêche de Constantine» (1947). Despite the importance of this earthquake in Northeast Algeria, it was studied only by Rothé (1950). He described briefly the effects of the shaking, quoting mainly the press as its source, and assigned maximum intensity at I_0 = VIII-IX (MS) at Oued Hamimine and its close surroundings. Grandjean (1954), quoting Rothé as its source, published an isoseismal map (fig. 1). Several other authors have assigned maximum intensity but without quoting their sources, that is at I_0 = VIII-IX (MM), (IMPGA); IX (MM), (Khemici, in EERI, 1983); IX (MM), (USCGS) and VIII (MSK), (SSIS).

The 1947 Constantine earthquake was recorded by most of the seismological stations operating at that time. Instrumental epicentre locations were calculated at 36.300°N, 6.700°E (ISS); 37.000°N, 8.000°E (USCGS). Macroseismic epicentre determined at 36.300°N, 6.666°E (Rothé, 1950); 36.27°N, 6.64°E (Ambraseys, 1981a) and at 36.300°N, 6.683°E (IMPGA). Magnitude was also calculated at M = 5.30 (IMPGA and IPG Strasbourg) and 5.0 (Karnik, 1969), m_b = 5.3 (Mezcua and Martinez, 1983).

3. Damage and casualty distributions

Many photographs (see Benouar, 1993), taken shortly after the earthquake, show the extent of the disaster which, in our point of view, was underestimated by the press reports. The information extracted, from the sources available to us, were care-

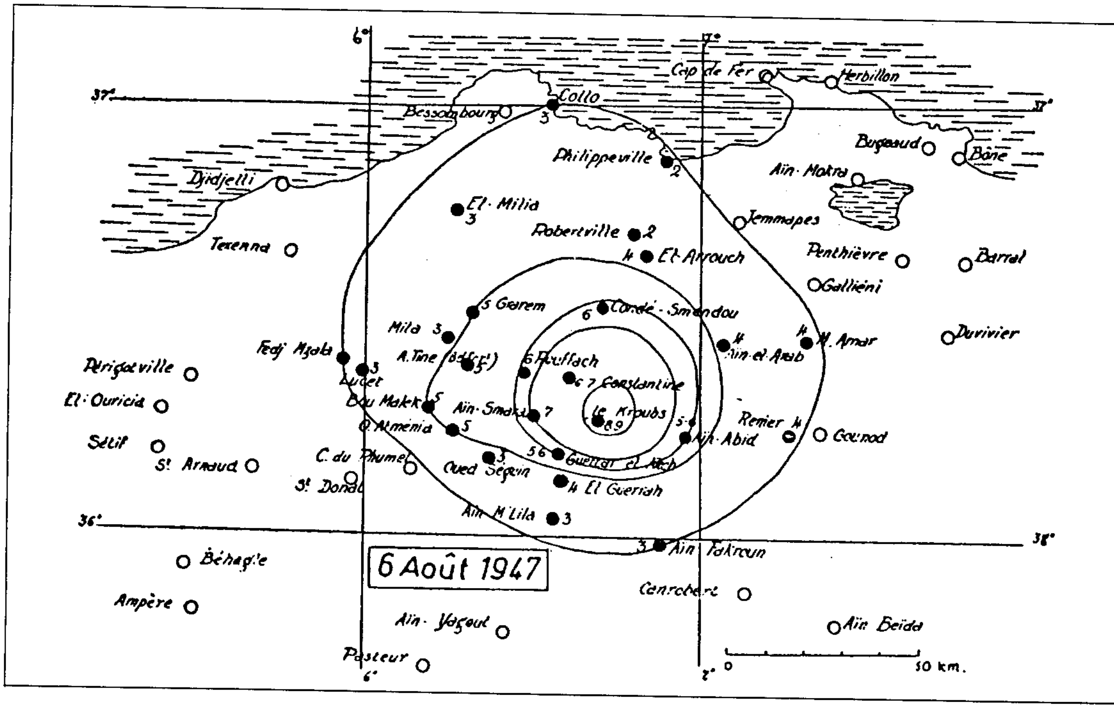

Fig. 1. Isoseismal map (in MS scale) of the main shock of the 6 August 1947 earthquake, after Grandjean (1954).

fully analyzed and contributed substantially in the reconstruction of the macroseismic field. The available macroseismic data describe quite well the effects of the shaking on humans, man-made structures and on the ground itself. Most damage, as reported by all the contemporary sources, was observed at Oued Hamimine (district of Khroub), about 13 km southeast of Constantine.

In Oued Hamimine the shaking caused the collapse of several houses trapping many people under the rubble. It is the farm of Agha El Hadef Eloki, located at 5 km north of Khroub beside the airport, that suffered most damage. The farm was reduced to a piling of stones, mud, wood and iron sheets. A family who was living in the 2nd floor, surprised in their beds, was totally buried under the debris of the building. Here, it is reported that at least 3 people were killed and 3 others were seriously injured. In the second farm of Agha El Hokki, 800 m away from the first one, the damage was more important. The central building which, however, was relatively well built, sustained serious damage. Hangars were flattened, crushing under their weights the farm equipment stored. Two people, who were close to the building during the shaking, were injured by the fall of removed stones from the walls. The farm Boudrali, built on a hillside, experienced damage beyond repair. Light hangars, adobe and stone constructions were mostly destroyed. In Oued Hamimine and its surroundings 20 farms were completely destructed and 20 others seriously damaged.

The low rate of casualty is mainly due to the fact that most people were already in the fields, and that most women and children were out in the gardens or courtyards where much of the daily life takes place, particularly in summer season.

In Constantine the earthquake had spreaded terror and general panic. The ground was shaken by a succession of shocks of different intensity and amplitude but all of them were intensively felt. The main shock occurred at 9 h 46 min with an exceptional violence. The duration of the shaking was, according to the Observatory of Alger, 24 s and 6 to 8 s as estimated at Constantine (Press, 1947). The Old Rock experienced a wave motion which seemed to be in the west-east direction. The shaking reached in few seconds a tremendous acuteness which had given a sensation of a rolling waves. The population was all in a flutter; men, women and children, under the emotion, had fled from their homes to the streets, public gardens and even out of the city, fearing the collapse of the constructions. Many people were camping in the surrounding woods for many days. The impression left by the main shock were so strong that they were interpreted by the same words and gestures. Constantine and its suburbs lived a continuous shaking all day long, the time interval of the shocks was varying between 2, 3 min to a half hour. The rumbling of the aftershocks and its reverberation in the gorge of the Rhummel accentuated the terror in the population. A witness reported that: «... Constantine was like a motor racing circuit; all the cars were loaded with luggage and people and rushing out the city to other safer destinations (countryside). In a short period of time, the city was totally deserted and no car was seen». The press reported that about 10000 people had left the town during that day. It was reported that many old constructions had suffered significant damage. At the numbers 49 and 19 of the Rue Bleue, the roofs and ceilings collapsed. Roofs and ceilings of the buildings, at the Rues Alexis, Lambert, Perregaux and Grand, were seriously damaged. More damage, as fall of ceilings, roofs, cracks in walls was observed in several places in the town of Constantine. It is also specified that some old tumbledown houses were not really victims of the earthquake but had seen their defectiveness fatally aggravated during the shaking. At the Welvert (Casbah of Constantine), a beam was removed by the earthquake injuring two people. Fall of two chimneys was reported at Place Courbet. Major deep fissures were also observed at 2 and 4 Rue Ledru-Rollin. Inside the apartments, it was an infernal saraband; several things were displaced, even projected, others like lustres and mirrors were crashed to the ground, and the furniture was shaken and jumbled in a spectacular crashing sound. Important fissures and large cracks in walls were observed in the city train station. The sore point of Constantine was the central market which, full of shoppers at the time of the shaking, experienced an unprecedent panic. Fortunately, the earthquake did not cause any fatality in Constantine itself (Press Reports, 1947). We should also mention that, if the Moslems and Jews habitations of the old parts of Constantine had suffered significant damage, in the other hand the modern reinforced concrete and ashlar buildings did not sustain any. The earthquake, fortunately, did not cause any damage to the lifeline systems (gas, electricity, water, sewage...), even the telephonic and telegraphic communications subsisted. Given the violence of the main shock, people inside the post office had left in general panic as well as the staff. In the gorge of the Rhummel, the hot springs, that usually feed the public bath establishment installed at the foot of the impressive cliff, exhibited some particular phenomena. The water, habitually limpid, suddenly became reddish and muddy after the shaking whereas the flow of the spring and the water temperature considerably increased. This situation lasted about a half hour. In the Platanes (district of Constantine), the farm known as «Ferme des Chasseurs» sustained moderate damage, a large section of a wall collapsed injuring one child. In Sidi Mabrouk (city of Constantine) where were built very cheap houses for the railwaymen, many cracks were observed on the facades and major damage was caused inside the constructions. The building, at number 7 Rue Sergent Alaize, was completely cracked from top to bottom. This part of Constantine was offering a touching scene to visitors. Several families, deprived of their homes by the earthquake, were camping in the open under army tents. Sidi M'cid (city of Constantine), known as the «beach of Constantine» because of its swimming pool, had known the same phenomena as the hot springs. The water of the swimming pool was reddish, muddy and releasing an unpleasant smell (sulphur gas). In Ain Smara, 15 km southwest of Constantine, several walls were cracked, tiles were removed and crashed to the ground, dishes and glassware were broken, furniture overturned and small bells rang. Rouffach, 13 km east of Constantine, had experienced slight damage as few cracks in walls and fall of ceilings. In Conde-Smendo, 20 km north of Constantine, fall of chimneys was observed as well as cracks in walls as well as in Guettar El Aich and Ain El Abid. In Oued Athmania, Belfort, Grarem, Ouled Rahmoun and Bou Malek, only slight damage, as fine cracks, was reported. In Ain El Arab, Medjez-Amar, El Guerrah, Oued Seguin, Mila, El Harrouch and Remier, the earthquake was felt by many people indoors and given the impression that a heavily loaded truck is passing.

The earthquake was reported as felt by few people at Robertville, Philippeville, Oued Seguin, Ain M'lila, Lucet, Ain Fakroun, El Milia and Collo.

According to Rothé (1950), without quoting his sources, the earthquake was not felt at Ain Abessa, Ain Beida, Ain Mokra, Ain Tagrout, Ampere, Arris, Barika, Barral, Batna, Biskra, Bone, Bordj Bou Arreridj, Canrobert, Chateaudun-du-Rhummel, Corneille, Duvier, El Madher, El Ouricia, Gallieni, Jemmapes, Khenchla, Mac Mahon, Medjana, Meskiana, Oued Zenati, Perigotville, Setif, Saint Arnaud, Saint Charles, Souk Ahras, Strasbourg, Tebessa, Tocqueville and Zeraia.

4. Intensity re-evaluation

Intensities were re-evaluated anew, with the reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) scale, by using all the macroseismic information extracted from a variety of sources available to us.

The assignment of intensities to the city of Constantine and its close surroundings has been relatively easy because of the good description of the numerous effects of the earthquake on humans, man-made objects and on the ground itself (Press, 1947). The epicentral area, at that time, was relatively densely inhabited (Armature Urbaine 1987, 1988). According to the history of the region, the building stock exposed to the shaking consisted mostly of structural types A and B, and a small percentage of type C as defined by the MSK scale.

After a careful analysis of the macroseismic data collected, maximum intensity exhibited was re-evaluated at I_0 = VIII (MSK) and allocated to Oued Hamimine and its close surroundings, an area of about 7 km radius. It was assigned to the zone where destruction of the gourbis and masonry structures (farms) were completely destroyed and there was loss of life. As in other parts of seismic Algeria, particularly, the native dwelling (gourbis) had shown a very low strength and an extremely high vulnerability to earthquakes. Thus, the degree of damage to this type of construction is generally an indication of the weakness of the structure rather than the severity of the ground shaking. As a consequence of the defectiveness of these structures, maximum intensity in any destructive earthquake seems to be the same. That is at intensity IX-X (MSK), most of these constructions are destroyed and any village would thus look equally, but no more, devastated at higher intensities of the scale.

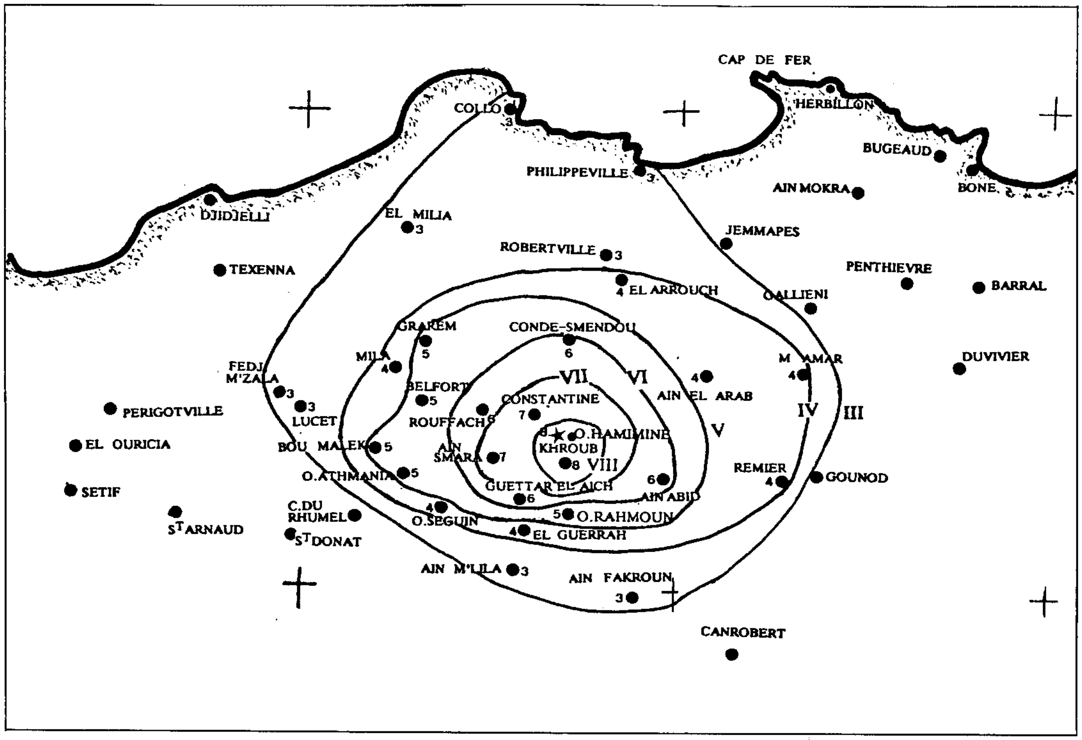

Fig. 2. Isoseismal map (in MSK scale) of the main shock of the 6 August 1947 earthquake. The star shows the macroseismic epicentre.

Higher intensities, in many parts of Algeria, can only be re-evaluated from the behaviour of official buildings, public work constructions and any other well built reinforced concrete structures.

Intensity VII was allocated to Constantine, Ain Smara and Sidi Mabrouk. Intensity VI was assigned to Rouffach, Guettar El Aich, Ain El Abid, and Conde-Smendo. Intensity V to Oued Athmania, Belfort, Bou Malek, Grarem and Ouled Rahmoun. These intensities are attributed with a rigid interpretation of the MSK intensity scale (Medvedev *et al.*, 1981). Intensity IV was attributed to Ain El Arab, Medjez-Amar, El Guerrah, El Harrouch, Oued Seguin, Mila and Remier. Intensity III, assigned to Phillipeville, Robertville, Ain M'lila, Lucet, Fedj M'zala, Ain Fakroun, El Milia and Collo, depicts the boundary of the felt area assumed, in the absence of very low intensity observations. These intensities were allocated on felt effects and on the evidence of lack of damage to low-quality constructions.

As a result of the analysis of the macroseismic data, an isoseismal map of the 6 August 1947 Constantine earthquake has been drawn and is shown in fig. 2.

5. Magnitude determination

The surface-wave magnitude of the earthquake is calculated from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 5 seismological stations located at distances between 14° and 19°, and a preliminary epicentre (macroseismic) at 36.314°N, 6.680°E. The data and the results are given in Benouar (1993). The mean period is 12.6 s and the derived value of M_S, without station corrections, is 5.00 (± 0.29).

6. Foreshocks and aftershocks

The main shock was preceded by slight foreshocks on 5 August 1947 at 21 h 45 min and 22 h 30 min (GMT) which were felt at Constantine. These foreshocks did not cause any damage.

On the other hand, the earthquake was followed by a long sequence of aftershocks, continuing until late December 1947. A witness, Professor M. Weil, had counted about 10, 4 between 10 and 11 h, 3 in the afternoon and 3 during the night. Besides the shakings, an infinite underground rumbling was perceived during more than 24 h with periods of perfect quiescence of 2, 3 min to half an hour, giving the impression of a deafening sound in the deep ground. Several of these shakings were felt in the surrounding villages as Ain Smara, Rouffach, Khroub and Ain Abid. The most violent aftershock occurred on 7 August at 12 h 30 min 2 s (GMT) with lesser duration; it was felt as far as the main shock and followed, up to midnight, by frequent oscillations. The population of Constantine was still trying to recover from the main shock when this strong shaking hit again. The shaking was most felt between Lamoriciere and Mansourah forest following the gorge of the Rhummel. In the Clemanceau street, Faubourg of El Kantara, the shock was so strongly felt that the population fled from their homes to the open. In fact, at more or less short time intervals, repeated jerks occurred in various directions. It was like a sort of a fever which, up to midnight, had kept Constantine and its surroundings in full distress. The damage caused was very similar to the one produced by the main shock to the old buildings (cracks, fissures, fall of plaster and ceilings). The hot springs of Sidi M'cid and the Rhummel, which after the main shock had debited reddish and muddy water, had shown the same phenomena but more pronounced. The renewed event of the 2nd day of the seismic crisis had raised, to the paroxysm, the nervous tension of the whole population of the area affected. The exodus was carried on for the people who found a shelter far from the emotions for which they could not resist. Karnik (1969) located the macroseismic epicentre of the largest aftershock at 36.3°N, 6.7°E and assigned a magnitude at 5.0.

7. Discussion

The 6 August 1947 earthquake is the largest event which occurred at Constantine since 1908. It was widely reported in the Algerian and French press. According to the seismic history of Algeria reported by Hée (1933, 1950), Rothé (1950), Grandjean (1954), Roussel (1971), Mezcua and Martinez (1983) and recently Benhallou (1985), Constantine region was many times the site of damaging earthquake during the last two hundred years. It is of interest to know that all reported destructive earthquakes in Constantine region were associated with a relatively long sequence of aftershocks and with at least one moderate-magnitude (M ≥ 4.0) aftershock.

The Constantine 1908 and 1947 earthquakes show the possibilities for a high degree of spatial and time homogeneity of seismicity in eastern part of the country and the consequences of this in the evaluation of seismic hazard in Algeria. Compilation and careful analysis of contemporary documents concerning this earthquake has led to the evaluation of the amount of damage produced and how the population behaved. From the analyzed macroseismic data, the following source parameters have been assessed: macroseismic epicentre at 36.314°N, 6.680°E (Oued Hamimine); shallow focus which is shown by the fact that the heavily destroyed area (I_0 = VIII) was limited to the region of Khroub (an area of about 7 km radius) and the relatively small area over which the shock was felt (a zone of about 65 km radius). The main shock and its aftershocks caused sufficient damage and panic to be recorded in contemporary documents. Because of the sparsely distributed douars and isolated hamlets, several intermediate sites within the radius of perceptibility, which could have enriched the macroseismic data, were not reported in any contemporary document available to us.

We should keep in mind that most damage was caused to adobe or stone houses while modern buildings did not suffer any significant damage. It is true that many of the traditional houses have suffered considerable deterioration through ageing, rain, earthquakes and mainly neglect and lack of proper repair. As a consequence of the weakness of these houses, the degree of damage is an indication of the defectiveness of these structures rather than the strength of the ground shaking. A detailed study of this destructive earthquake provides a fundamental tool for the mitigation of future seismic disasters by recommending ways of improving local construction procedures, building materials, layout and implantation of new urban and rural sites. Because the affected region displays many of the humans and geographical characteristics found in other seismic zones of Algeria, a careful analysis of the macroseismic data collected, relative to the 1947 Constantine earthquake, is therefore pertinent to Eastern Algeria as well as to the whole of the country, in terms of seismic risk and hazard assessments.

For historical events, contemporary documents as the press reports are generally rich in details and an indispensable aid in establishing chronology. However, these documents should be carefully analyzed, with in mind the context of political, socioeconomic, and demographic conditions, cultural, and religious background and the characteristics of the building stock of the period concerned. Algeria, since the killing of 45000 native Algerians on 8 May 1945 besides the consequences of World War Two, was living an unstable political and precarious socio-economic situations. That period was characterized for the native people by deception, racial segregation, unemployment, lack of adequate housing (up to 10 per room) and medicine. As it was reported at that time (Press, 1947): «... In the misery of the time, the vision was far beyond the recent disaster. The region was experiencing a serious political and socioeconomic problems which made the earthquake, for the natives, fall into a second-place...».

The total number of casualties officially reported was small, 3 dead (natives) and the number of injured, which was certainly much higher, was not communicated. The press (1947) gives 3 dead and 8 injured. We believe that the exact toll of casualties may never be known, as many victims were buried immediately after the earthquake to conform the Islamic law and were either not reported or simply voluntarily omitted by the administrative authorities for some reasons which are discussed in section 1. Chapter I.

Although the damage, officially reported, was due to the main shock, the possibility of cumulative damage from early aftershocks remains possible.

According to Rothé (1950), the Constantine earthquakes are caused by the settlement of the rock, on which is built the town, in crushing significant cavities formed at its base, about 1000 m deep, by dissolution.

Summarizing the results, we obtain the following data for the 6 August 1947 earthquake: origin time 9 h 46 min 38 s (GMT); macroseismic epicentre at 36.314°N, 6.680°E; focal depth about 10 km; maximum intensity I_0 = VIII (MSK); magnitude M_S = 5.00 (± 0.29).

ANNALI DI GEOFISICA, VOL. XXXVII, N. 4, July 1994

The Kherrata earthquake of 17 February 1949

Abstract
This research examines one of the largest earthquakes which occurred in the Babor ranges in this century. The Kherrata earthquake, which occurred at 21 h 1 min (GMT) on 17 February 1949, was the largest recorded event in the region since the beginning of this century. It caused significant damage to a relatively small area, Kherrata and its close surroundings, about 20 km radius. The village of Kherrata (surrounding dependent douars), which suffered most, was the centre of the affected area. The main shock, which lasted about 10 s at Kherrata, caused the loss of 2 lives, injuring about 16 and making approximately 350 homeless; it destroyed or seriously damaged about fifty housing units. The earthquake was associated with large fissures and important rockfalls and landslides which obstructed many roads of the region. It was preceded by many foreshocks and followed by a long sequence of aftershocks. We learned from the contemporary documents that the region has experienced heavy rain, high wind and a snowstorm, few days before the earthquake, which may have caused some damage or at least weakened local adobe houses of the affected zone. After much analysis of the macroseismic data extracted from the variety of sources available to us, maximum intensity I_0 = VII (MSK) was assigned to Kherrata and its close douars, an area about 7 km radius. The main shock was widely felt as far west as Bordj Menaiel, south as Davout, east as Djidjelli and north to the coast, an area about 16000 square km. The surface-wave magnitude was calculated, without station corrections, at 4.75 (± 0.07). The damage was estimated to about 300 million French Francs.

1. Introduction

Since the beginning of the new year (1949), a dramatic fatality had stricken the picturesque region of the famous Chabet El-Akhra which seems willing to remind the population that it really deserves its name «Pass of the Last Judgement». Particularly in 1949, the region of Kherrata was the centre of an intense seismic activity. Few days before the main shock, the affected region lived a torrential rain (420 mm in less than 36 h) followed by a windstorm and then the snow, naturally rushing down from the high surrounding mountains, formed real torrents which started their devastating action. Then at last, a violent earthquake, which occurred on 17 February 1949 at 21 h 1 min (GMT), struck the affected region to finish off the work previously undertaken by the forces of nature.

According to the seismic history of the region reported by Rothé (1950), Grandjean (1959), Hée (1933 and 1950), Roussel (1973) and recently by Benhallou (1985), it was by no means an unattended earthquake. The epicentral zone, located in the Babor ranges, was the site of few major earthquakes and many more small ones in the last two hundred years. The seismic history of the region shows that the seismic activity is relatively moderate and constant in the Babor ranges, about 5 shakings per year and a stronger earthquake every two years (average) with a macroseismic area equivalent to that of 15 January 1949. Certainly, a complete study of the larger events of the region will provide valuable information for seismic hazard evaluation in the restricted zone and as well in the whole of Northern Algeria, since many of the human and geographical characteristics found in the Babor region are very common in other parts of the country.

The shaking was felt, in a relatively small area about 85 km radius, between Djidjelli in the east, and Bordj Menaiel in the west (about 240 km), and Tixter and the coast (about 100 km). The main shock, which lasted between 15 and 20 s, caused the loss of 3 lives, injuring 16 and making more than 350 homeless; it destroyed or severely damaged about fifty housing units. The main shock caused significant to slight damage to the douars of Kherrata, Djermouna, Riff, Oued Marsa, Bougie, La Reunion, Ouled Embarek, Taskriout, Aidriss and Beni Ismail, an area about 40 km radius. Maximum intensity is re-estimated at VII (MSK) and is allocated to, where most damage was observed, Kherrata and its surroundings, an area about 7 km radius. The surface-wave magnitude is calculated at, without station corrections, 4.75 (± 0.07).

The earthquake was associated with major fissures, rockfalls and landslides, particularly between Kherrata and Ouled Houri (douar Ferhous); a 50 m long fissure with 30 cm vertical displacement was produced. At the gorge of Chabet El-Akhra, many rockfalls obstructed the national road and damaged the parapets in several places.

The main shock was preceded and followed between 5 January and the end of May by at least 61 shocks. The foreshocks started on 5 January and continued at the frequency of 2 to 3 per week; they were accompanied by an impressive underground rumbling. Some foreshocks were strong enough to cause damage to the adobe houses already weakened by the heavy rain. The earthquake was also followed by a long sequence of aftershocks which accentuated the destruction of the gourbis already affected and caused slight damage, such as fine cracks, to relatively well built constructions. It is of interest to notice that the main shock (17 February) did not occur in the beginning of the sequence but slightly in the middle of the seismic crisis.

2. Sources of information

To reconstruct the macroseismic field of this earthquake with an appreciable degree of reliability, an important search for contemporary documents relative to this event was carried out in various libraries and archive centres. The macroseismic data retrieved from the various sources available to us, have improved substantially our knowledge of the effects of the earthquake and contributed considerably to its reconstruction. This event was largely commented in the Algerian press (1949) which relates also the heavy rain, wind and snowstorm in the same period. The most extensive account is given in «La Dépêche de Constantine» but with no photograph of the damage. The 17 February 1949, according to the various sources we have analyzed, is by far the largest event in the Babor in this century. In spite of the particular importance of this destructive earthquake for the Babor, only Rothé through a field visit in March 1949 to the affected area, accompanied by Dalloni who had previously reported the effects of the earthquake to the General Governor of Algeria (Press, 1949), has studied the event, assigned maximum intensity VII (MS) to the most affected zone and published an isoseismal map (fig. 1). Grandjean (1954), quoting Rothé as his source, published an isoseismal map (fig. 2).

In the recent catalogues, instrumental epicentre location was given at 36.5°N, 5.20°E (ISS) and 36.00°N, 5.50°E (USCGS), and macroseismic epicentre at 36.5°N, 5.25°E (Rothé, 1950). Maximum intensity assigned to this earthquake is: VII (MSK), (IMPGA); VIII (MSK), Karnik (1969) and VIII (MM), Khemici (in EERI, 1983) VIII, using the special note of Rothé

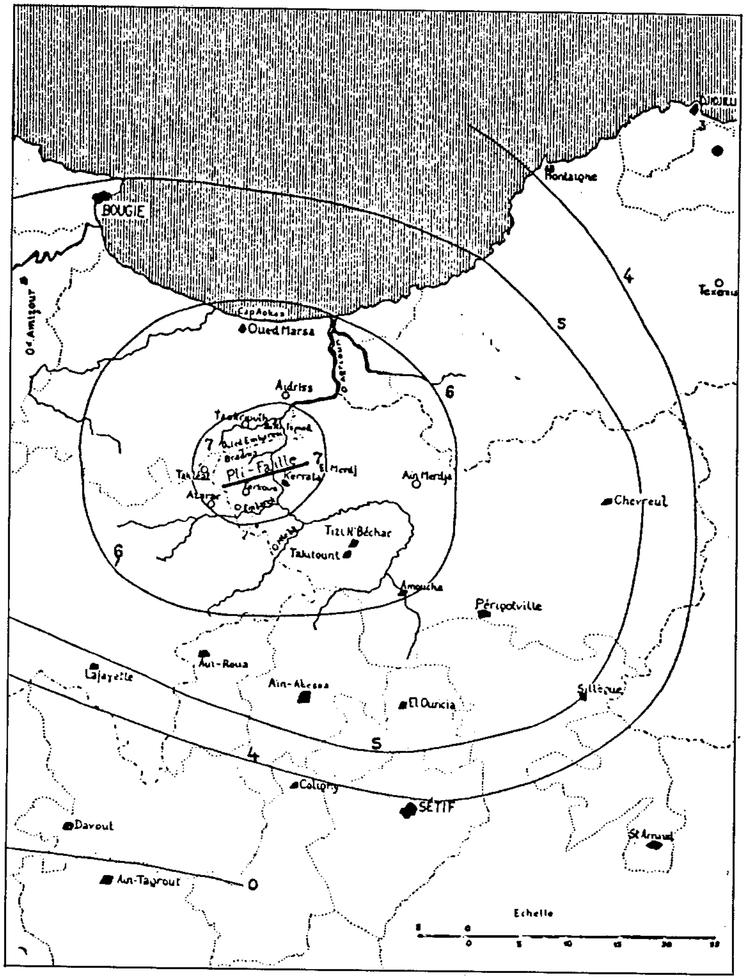

Fig. 1. Isoseismal map (in terms of MS scale) of the main shock of the 17 February 1949 earthquake, after Rothé (1950).

(1950). Magnitude of the event was also determined at 4.90 (Rothé, 1950) and 5.2 (Karnik, 1969).

3. Geographical aspects of the epicentral region

Kherrata, the centre of the epicentral region, is located about 200 km east of the capital Alger, in the Babor mountains. East of the Soummam valley, stretch the Babor ranges in prolongation of the Djurdjura chains. The highest relief of these mountains is constituted by limestone rocks as in Kabylie; the Grand Babor is culminating at 2004 m and the Trababor at 1965 m. The rivers cross the mountain ranges by narrow and deep gorges of which is the well known of Oued Agrioun (Chabet El-Akhra), pass

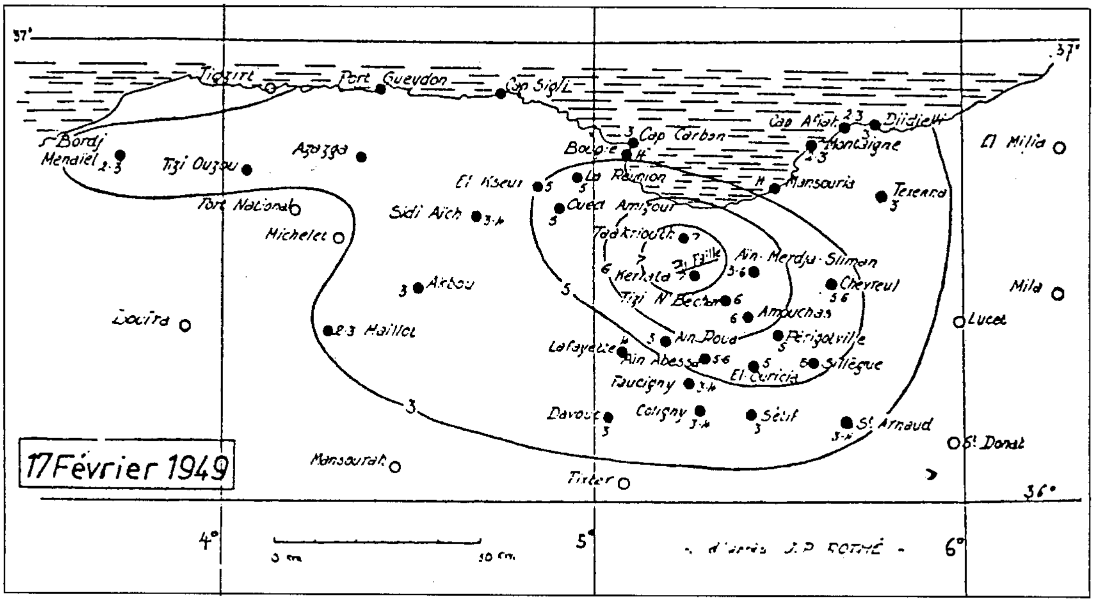

Fig. 2. Isoseismal map (in terms of MS scale) of the main shock of the 17 February 1949 earthquake, after Grandjean (1954).

of about 7 km long notched into the limestone massif of Kherrata. The massif of the Babors is characterized like the Tell Atlas by intense folding with some remarkable particularities: all along the gorge of Chabet El-Akhra, limestone is erected till the vertical and sometimes beyond. Folding hinges are shown in several sites, anticlinal or synclinal, grouped together in parallel bundles, approximately directed from west to east (Rothé, 1950). The deep valleys in the different Oueds form real borders between the douars. The region is characterized by numerous douars with red tile roof in the valleys or on the crests of the mountains. Apart from official buildings, public work constructions and settlers houses, all the other houses were made of limestones with a mud mortar. These local traditional houses or gourbis are single floor constructions whereas the well built French buildings were two to three storey high. In some parts of the region, douars and isolated hamlets are simply built on mass of fallen earth with high slope and in other places built against enormous rocks which have fallen from the cliff, generally close to small springs which are used for daily life, irrigation of their vegetable gardens and cattle.

The Babor region is, however, from the point of view of climate and vegetation, one of the most beautiful sites in Algeria; it contains a large forest wealth besides the mineral resources as lead, zinc, copper and iron. The depressions of the region are rather used for cereal harvest while the old massif is reserved for orchards; but the native peasants, like all the Mediterraneans, are particularly gardeners. They grow the fig, olive, vine and oak trees which share together the heights of the mountains with the ash tree.

4. Damage and casualty distributions

The macroseismic data retrieved have substantially contributed in the re-assessment of the effects of the shaking in the region and in the determination of the characteristics of the earthquake. The data available describe quite well the impact of this event on humans, man-made structures and on the ground itself. Most sources concentrate on the destruction of Kherrata and its surrounding douars, particularly the douars of Djermouna and Ferhous where most damage was observed. The epicentral zone encompasses major parts of the districts (Commune mixte) of Oued Marsa, Guergour and all the territory of the district of Kherrata (known in the past as district of Takitount).

Kherrata, already hit on 15 January by a foreshock which destroyed 30 gourbis and weakened a lot more, was the site of a destructive earthquake on 17 February, 1949 at 21 h 1 min (GMT). One account from the village reported that: «... It was 21 h 1 min when the shaking started and my alarm clock in its fall stopped at that time which is still indicating...». The main shock was accompanied by an impressive underground rumbling. The rumbling of the earthquake added to the roaring of the waterfall, of Oued Agrioun, which reverberated for a long time, produced an infernal sound in the region. The oscillations were oriented southeast and northwest in the same direction, in a global scale, as of the Babor ranges. The electric cables were cut in many places which put the whole village of Kherrata in total darkness. It was a general comprehensive panic; the whole population was all in a flutter. All the inhabitants, in a state of utter confusion, left their homes (in the screaming of women and children) to camp in the open all night long, fearing stronger shock. Babies wailing, wrapped in a hurry in blankets, children crying and grasping the clothes of their scared mother and men seriously frightened, that what was the spectacle in Kherrata on Thursday 17 February 1949. In about 10 s, many of the inhabitants have lost their goods and their houses and did not have any shelter from the rain and the wind. It is of interest to mention that besides the earthquake, the region experienced torrential rain and windstorm during that period. Frightful crushes of the walls and roofs were like explosions. In the morning, after having counted its deaths and injured, Kherrata was looking to the ruins left by the earthquake. Certainly, the constructions of the village were not all destroyed but all suffered seriously and some of them were damaged beyond repair (Press, 1949). Kherrata was a colonization village where the constructions were relatively well built compared to the native gourbis. The buildings were of ordinary masonry or reinforced concrete structures. At the village of Kherrata itself, the damage was slight and not significant except at the gendarmerie buildings where the partition walls were fissured and loosened. The cracks, fine at the tops of the walls, were widening toward the bottom in a southwest direction. The house of the medical doctor and the church bell tower were seriously damaged. The surrounding douars, where the native gourbis were made of «toub» or drystones and mud mortar, sustained much more damage. The gourbis have seen their walls shattered and their roofs destructed. Important rockfalls, in the gorge of Chabet El-Akhra, obstructed the national road 9 and damaged the parapets between Bougie and Setif, which interrupted the road traffic for several days. Total number of casualties at Kherrata and its surrounding douars were very small, one dead and 16 injured (Press, 1949).

In Oued Marsa, located on the coast at about 20 km north of Kherrata, the main shock, which lasted between 15 and 20 s, had strongly shaken the constructions on the whole district territory. In the douar of Riff (district of Oued Marsa), where most damage was observed, the convent school of Sainte Madeleine at Beni Ismail sustained so much damage that it had to be evacuated. The partition walls, the roofs and the pinnacle of the church collapsed, other sections of walls were largely opened and their bricks removed. Two wine reinforced concrete vats were so cracked that 50 hl of wine were lost. Amphoras were broken. The building as a whole was no more than ruins except the entrance. The ground near the garage of the convent was seriously cracked, fissures of 4 to 5 m long over 2 to 3 m wide and a variable depth were observed at the site. More damage was caused at Ouled Embarek where the school was badly cracked, and at Taskriout where several gourbis were cracked and sections of walls collapsed. In Cap Aokas and Aidriss public buildings of the district of Oued Marsa relatively well built, were cracked. It was reported that, in Cap Aokas and Kherrata, the local traditional houses were not destructed whereas the French higher buildings were affected. The damage caused by the earthquake, on the territory of Oued Marsa, was estimated at about 9 million French Francs of which 6 at the convent. In the douar of Dra el Caid (northeast of the district of Guergour), the Takleat section had sustained major damage, 18 housing units were partly destroyed. The douars of Djermouna and Ferhous had suffered major damage. In Ouled Houri (douar Ferhous) many gourbis were destroyed. The country road was seriously cracked between this douar and Kherrata, a fissure of 50 m long with a 30 cm vertical displacement was reported. At Bradma, in the valley of Djermouna, several gourbis were destroyed and 2 people were killed. In the valley of Oued Embarek, the farm Maida, which is about 9 km away of Kherrata, was severely damaged (sections of walls destructed and fall of chimneys). In Bordj Mira an underground rumbling was perceived with an impressive continuity. The main shock, which lasted about 9 s, was violently felt at Bougie, located on the coast at about 45 km northeast of Kherrata, but no damage nor casualty were reported. In Ziama Mansouriah, located on the coast at about 27 km north of Kherrata, the main shock, which lasted about 9 s, was strongly felt but did not cause any damage nor casualty. Oued Amizour, at about 37 km northwest of Kherrata, was not spared by the earthquake as well as its surrounding villages and douars. The shaking was severely felt but no damage nor casualty were declared. Repercussions of the main shock were observed up to Setif, situated at 36 km south of Kherrata. Important cracks on the ground were observed near the Mosque and Dar El-Askri of which the surrounding wall was seriously cracked in several places and had to be rebuilt. The most remarkable fissure of the ground was, that starting from the Mosque and crossing Dar El-Askri to reach the watering place, about 600 m long. In Amouchas, Chevreul, Ain Merdja, Ain Abessa and Tizi N'Bechar, the constructions experienced moderate to small damage such as small cracks in walls and fall of plaster. In Bougie, Darguinah, Ain Roua, El-Ouricia, Ain Cherchera, El-Kseur, Oued Amizour, La Reunion, Setif, Sillegue and Perigotville, the local traditional houses have experienced slight damage; houses were shaken enough to awake many sleeping people. In Yakouren, Azzazga, Ziama Mansouriah, Lafayette, Faucigny, Coligny, Sidi Aich, Maillot, Tizi Ouzou, Bordj Menaiel, Texenna, Djidjelli, Davout and Saint Arnaud, no damage was reported but the main shock was widely observed. We found no evidence that the shaking was felt beyond these last sites. As we remark, it is all the region between the gorge of Kherrata and the littoral, following a axis oriented southeast-northwest, that suffered most.

5. Intensity re-evaluation

All the macroseismic data retrieved from the various sources were used to re-assess the effects of the earthquake and to re-evaluate the intensities wherever possible, with the reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) scale. For a better appreciation of the strength of the shaking, a comprehensive investigation was carried out to reveal what type of constructions existed and in what state they were, in order to add the macroseismic information already collected, and thus to re-assess the intensities with a certain degree of reliability. From contemporary documents, we learned that three types of constructions existed when the 17 February earthquake struck the Babor region. These constructions may roughly be summarized as reinforced concrete structures, ordinary and reinforced masonry and local traditional adobe or drystone houses (gourbis) classified respectively as type C, B and A, according to the MSK scale. As in most parts of Algeria, apart the official buildings which were reinforced concrete structures, the settler houses, generally built with ordinary masonry, and the majority of the native people housing were adobe or drystone gourbis. More than three-quarters of the traditional houses in the region are very old constructions. These houses are one floor construction with thick brittle walls (adobe or drystone) and heavy roofs (mainly tiles) with loose or no connection between these elements. Many of these old houses have suffered degradation through ageing, negligence, improper repair, heavy rain and earthquakes. Sites of the older douars are most commonly found on the top and flanks of the mountains or in valleys. Typically, the traditional gourbis have shown a high vulnerability to earthquakes and even to heavy rain. According to the Algerian history, a large number of these constructions were seriously damaged or totally destroyed by downpour which gives a proof of their inherent weakness.

After a careful analysis of the macroseismic data, maximum intensity was re-estimated at VII in the MSK scale and assigned to Kherrata, douars Djermouna, Ferhous, Bradma, Ouled Embarek, Beni Ismail, Takleat, Azarar and Taskriout. Intensity VI to Amouchas, Chevreul, Ain Merdja, Ain Abessa, Oued Marsa, Cap

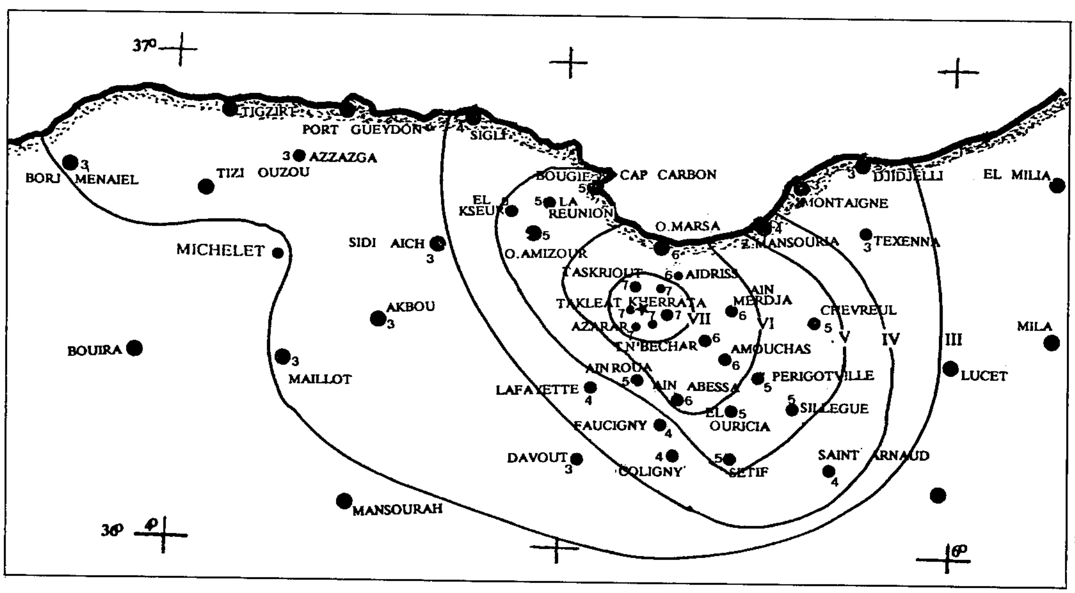

Fig. 3. Isoseismal map (in terms of MSK scale) of the main shock of the 17 February 1949 earthquake. The star shows the macroseismic epicentre.

Aokas, Aidriss, Tizi N'Bechar and Takitount. Intensities VI to VII are assigned to sites that contain reinforced concrete structures slightly cracked, masonry constructions with small cracks and few adobe houses destroyed which are consistent with a rigid interpretation of the intensity scale (Medvedev *et al.*, 1981). Intensity V was assigned to Bougie, Darguinah, Ain Roua, El-Ouricia, Ain Cherchera, El-Kseur, Oued Amizour, La Reunion, Setif, Sillegue and Perigotville. This intensity is allocated to sites where the earthquake was strongly enough felt by the population and only slight damage was produced. Intensity III-IV was allocated to Azzazga, Yakouren and Ziama Mansouriah. Intensity III to Lafayette, Faucigny, Coligny, Sidi Aich, Akbou, Maillot, Bordj Menaiel, Texenna, Djidjelli, Davout, Saint Arnaud and Cap Afia. Intensities III to IV were assigned solely on felt effects and on the evidence of lack of any damage to poor-quality types of constructions. Intensity III^+ depicts the boundary of the felt area, assumed, in the absence of very low intensity macroseismic data.

As a result of the analysis of the macroseismic data available an isoseismal map of Kherrata 17 February 1949 earthquake has been drawn and is shown in fig. 3.

6. Magnitude determination

The surface-wave magnitude of this event has been calculated from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings, from 2 seismological stations, and a preliminary epicentre (macroseismic) at 36.518°N, 5.236°E. The data and the results are shown in Benouar (1993). The mean period is 10.6 s and the derived value of M_S, without station corrections, is $4.75(\pm\ 0.07)$.

7. Foreshocks and aftershocks

The main shock was preceded and followed between the 5 January and the end of May 1949 by numerous tremors of less intensity.

According to the press (1949), since the shakings of the 5, 6 and 7 January, the ground was continuously shaking at Oued Marsa and Kherrata at the frequency of 2 to 3 tremors per week which seriously undermined the spirits of the population. A sequence of larger intensities started on 15 January by three foreshocks recorded at Alger (IMPGA) at 10 h 51 min, 11 h 14 min and at 13 h 26 min. The most significant shaking, which caused considerable damage in the region of Kherrata, was that of 11 h 14 min which destroyed 30 gourbis at the douar Djermouna and was felt in area about 25 km radius. Maximum intensity of this foreshock was assigned at V (MS) by Rothé (1950) and VII (MS) by Karnik (1969) to Oued Marsa, Tizi N'Bechar, Ain Merdja and Perigotville. More tremors were reported, at Oued Marsa and Kherrata, on 16 January at 3 h 48 min and 21 h 33 min, 17 January at 1 h and 4 h, 18 January at 13 h 24 min, 7 February at 3 h 15 min, 9 February at 4 h 15 min and 15 February at 5 h 20 min which caused cracks in ceilings and significant fissures in old houses.

In the other hand, the main shock was followed by a long series of aftershocks, continuing until the end of May. The early aftershocks occurred at the frequency of two to three per day, accompanied by underground rumbling which caused a sensation of insecurity in the whole epicentral region. The largest aftershock occurred on 22 February at 4 h 5 min. According to the press (1949), it caused the destruction of 33 gourbis, weakened by earlier shocks and rain, at the douar Dra El-Caid (district of Guergour). The aftershock of 27 February at 2 h 48 min was strong enough to be felt in an area of about 20 km radius around Kherrata (Rothé, 1950). A witness in Kherrata reported that he counted 61 shocks during the period 15 January to May 1949.

It is of interest to mention that the main shock occurred in the middle of the seismic crisis that hit the Babor region during the period 5 January to the end of May.

8. Discussion

According to the historical seismicity of the Babor region reported by Rothé (1950), Grandjean (1959), Hée (1933 and 1950), Roussel (1973) and recently Benhallou (1985), it appears that this region is one of the most seismically active zones in Algeria, in terms of number of low intensity earthquakes (an average of 5 shakings per year), where the frequency of major earthquakes is low.

The reconstruction of the macroseismic field of the 17 February 1949 earthquake is of great interest for diverse reasons. Firstly, it represents the largest recorded seismic event in this area in the last two hundred years. Secondly, the epicentral area (Kherrata and its surrounding douars) displays many of the human and geographical characteristics found in other seismic zones. Therefore, a careful analysis of the effects of this event is pertinent to whole Northern Algeria, in terms of seismic hazard and risk evaluation. The Kherrata 1949 earthquake had shown the possibilities for a higher degree of spatial and time inhomogeneity of seismicity in the Babor and the consequences of this in the establishment of seismic hazard in Algeria. Compilation and careful analysis of contemporary documents related to the 1949 Kherrata earthquake have led to a detailed re-assessment of how much damage was produced to man-made objects, and to nature and how it was felt by the population. The damage caused to local traditional houses was, not only, the result of the strength of the ground shaking but also of the state of degradation of many houses. It is true that many of the traditional houses (gourbis) were already deteriorated by rain, earthquakes and lack of proper repairs. Thus, it is not easy to consider the real damage produced by the earthquake alone and particularly by the main shock since it occurred in the middle of the seismic crisis. However, careful and critical analysis of all the factors, that may have been involved in the damage such as rain, earthquakes, type of building stock and state of the structures, was necessary in order to obtain a realistic intensity re-evaluation and avoid overrating. According to the MSK scale, the main shock exhibited a maximum intensity in the range of VII-VIII within an area of 10 km radius. At first analysis, we were tempted to assign maximum intensity at VIII, but in considering carefully the type and the state of the building stock of the region, we were convinced that the damage was the result of the poor-quality constructions rather than the severity of the ground shaking. Thus, maximum intensity VII was allocated to Kherrata and its surrounding douars, an area about 10 km radius. Although most damage was reported as due to the main shock, the possibility of cumulative damage remains from foreshocks, early aftershocks and rain.

In order to study the earthquakes of the past critically and understand the information contained in the contemporary documents, the historical, socio-economic, and demographic situations, cultural and religious backgrounds and the characteristics of the building stock of the period concerned must be taken into account. In this century, and particularly since the end of World War Two and the massive killing of 45 000 native Algerians, asking for independence, on 8 May 1945 by the French army, Algeria entered a very unstable political phase characterized by discrimination and repression. The precarious socio-economic situation of the natives, as in other parts of the country, was characterized by a scarce agriculture, unemployment, and lack of adequate housing, schools and hospitals. The fact that this earthquake coincided with an unstable period was not profitable in terms of casualty and damage reports. It was thought that the information on this earthquake, as on other events, would be important, particularly in the press. Unfortunately, this was not so; the information contained in the press was limited to large douars and villages. Several sparsely distributed douars and hamlets in the valleys and on the flanks of the mountains in many intermediate sites within the radius of perceptibility, which could have enriched the macroseismic data, were not mentioned. We found curious that no photograph of the damage was published in any newspaper. As in previous events, the French authorities reported the information in a way to show stability and security for the settlers and to conceal the continuous and growing dissatisfaction of the native Algerians. The problem of the information in the native Algerian settlers, during the colonization period, is discussed in section 1. Chapter I. This may explains the reason that human and property losses were disproportionately small for houses of this type (gourbis). The press (1949) reported that the main shock and its aftershocks caused the loss of 2 lives, injuring 16 and destroying about 50 gourbis while Rothé (1950) mentioned only 2 victims and 18 gourbis destroyed. It was also reported that the foreshock of 15 January 1949, which was 8 times less strong than the main shock (Rothé, 1950), destroyed 30 gourbis and the largest aftershock, which was much less stronger, destroyed 33 (Press, 1949). We presume that, according to the reported damage caused by these secondary shocks, the damage caused by the main shock was underestimated as well as the casualty rate. In similar situations, more important information can inferred from historical military sources which, unfortunately, are not available to us today.

Summarizing the results, we obtain the following final data for the 17 February 1949 Kherrata earthquake: origin time 9 h 1 min (GMT); macroseismic epicentre at 36.518°N, 5.236°E; focal depth of about 8 km; maximum intensity I_0 = VII (MSK); magnitude M_S = 4.75 (± 0.07).

The Orléansville earthquake of 9 September 1954

Abstract
This research presents the study of the earthquake which occurred in the Orléansville region on the 9 September 1954. A twelve-second earthquake at 1 h 4 min 37 s on Thursday 9th of September, 1954, caused widespread destruction, killing or injuring thousands of people and trapping many survivors under the rubble in Orléansville, a town of 32000 inhabitants, and its surrounding region. The magnitude of this earthquake is re-calculated at $M_S = 6.7$ ($\pm$ 0.2). The main shock was followed by a long sequence of over 350 aftershocks during three months. The largest one occurred on 10 September 1954 at 5 h 45 min with a surface-wave magnitude $M_S = 6.3$ ($\pm$ 0.35) which completed the destruction of already weakened buildings in the region affected. Maximum intensity reached X in the MSK scale at many villages and douars of the region bounded by the Dahra range in the north and the Ouarsenis in the south. The radius of perceptibility was fairly large, and the shock was felt as far as Tizi Ouzou (east), Oran (west), well beyond Tiaret (south) and north up to Alicante, Granada and Cartagena in Spain with intensity II-III (MSK). The earthquake caused a loss of 1409 lives, injuring about 5000 and making 50000 homeless; it destroyed more than 33000 buildings, houses or gourbis and seriously damaged the very important hydraulic work system of the region. The time of occurrence and the low resistance of the constructions to earthquakes were the major cause of the high casualty rates. This earthquake caused considerable economic losses and had a large socio-economic and psychological impacts on the region.

1. Introduction

On Thursday 9th of September 1954, at 1 h 4 min 37 s GMT, the region of Orléansville and its surroundings, which is at about 150 km southwest of the capital Algiers, were hard hit by a violent earthquake. The main shock was recorded by the majority of the seismological stations in the world operating at that time. The duration of the ground shaking at Orléansville was 12 s. By the number of people killed, injured, made homeless (respectively 1409, 5000 and 50000) and the 33000 houses and gourbis destroyed, the 9 September 1954 Orléansville earthquake constitutes a major natural disaster for the region. It may be considered as the earthquake which most affected Algeria during the last 100 years, naturally before the El-Asnam 10 October 1980 earthquake. But in terms of the seismic history of Algeria, actually we are not able to classify this event since the historical seismicity had never been really studied. However, as far as we know, the Cheliff Valley has been, since 1911, the site of more than fifty earthquakes but was heavily affected by those which occurred in 1922, 1928 and 1934.

The shaking was widely felt in Algeria, in an area of about 220 km radius, as far as Tiaret in the south, Tizi Ouzou in the east and Oran in the west. Up north of the affected region, the earthquake was felt in many southeastern parts of Spain as

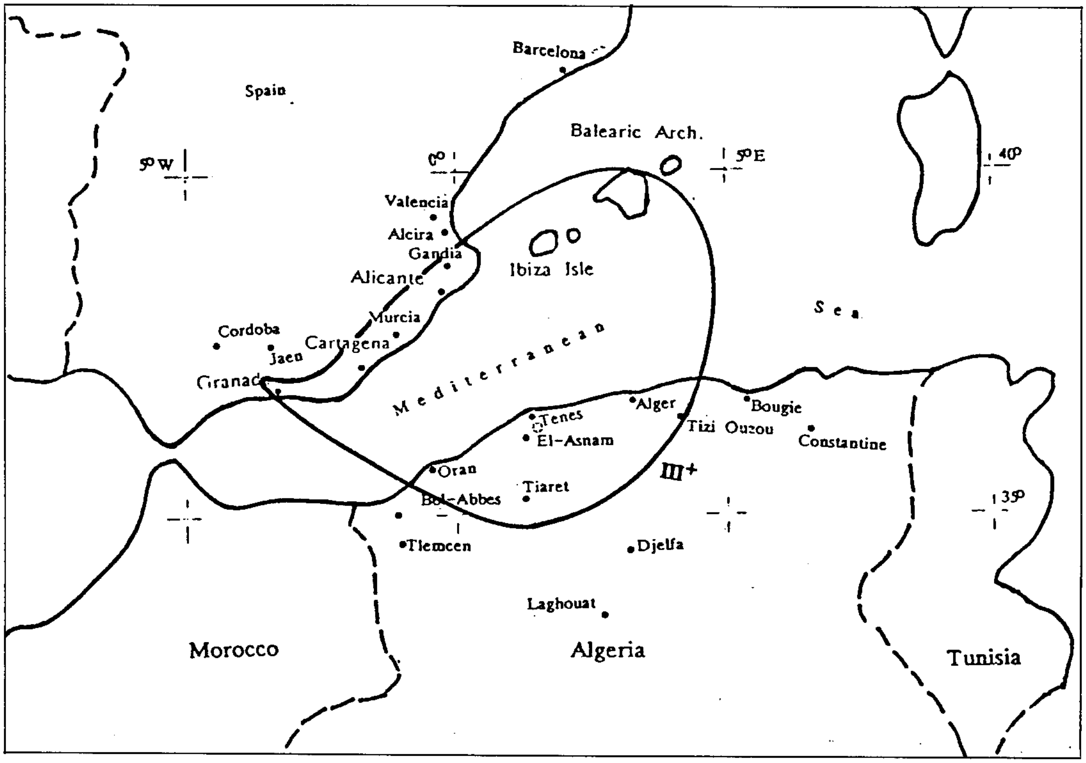

Fig. 1. Map of the affected region by the 9 September 1954 earthquake showing the approximate area of intensity III$^+$ (MSK). The star shows the macroseismic epicentre of the main shock.

Granada, Alicante, Cartagena, Ibiza island and the Baleric archipelago (fig. 1).

The earthquake occurred without any precursor signs. For hundreds of kilometres around, damage had been observed, particularly the direct impact on humans, such as human life loss consequences of the destruction of their houses. The most affected site, in terms of damage to man-made structures and to the landscape as well as casualties among the humans and their animals, was reported to be on the hills of Beni Rached in a locality called «Marabout (Saint) Sidi Djillali». In the epicentral area, a major fracture of a total length of over 20 km was observed surrounded by many bundles of breaks that seriously slashed the soil. This earthquake had caused spectacular deformations to the soil, mainly in the Beni Rached region just as to the zone located between Ponteba and Oued Fodda. Some of these deformations had shown a vertical displacement over 250 cm. Sand volcanoes indicating liquefaction of the soil were reported to be observed around the «Marabout Sidi Djillali» and the village of Beni Rached. The hydraulic system of the whole region had suffered a considerable damage. Another remarkable fact, not of less importance, which occurred during the shaking is that several submarine telegraphic cables linking Oran to Marseille (France), Oran to Gibraltar (Spain) and Gibraltar to Malta were snapped off the

Algerian coast in a zone of about 40 km from Tenes at a depth between 2200 and 2500 m.

2. Sources of information

An important search for historical sources relative to this earthquake was conducted in many libraries and archives. The collection of various types of contemporary documents assembled in this study presents a good picture of the event in all its aspects. These historical sources could be classified in two types which are the scientific work and the general public information (newspapers). The first type includes published scientific papers describing the damage caused to the area affected by the shaking, studying the geology and the seismicity of the region, and sometimes even determining some characteristics of the earthquake. The second type, although is written for the general public, in general, presents the impact of the earthquake, according to the political circumstances, with some exaggerations or simply negligence. Most of this type of documentation contains detailed information mentioning names of the damaged villages, douars, and even houses and buildings, behaviour of the population, organisation of the relief, photographs, narrative interviews of the people... etc. One must analyze very carefully all the information extracted from various sources before re-evaluating the damage caused by the event.

In spite of the importance of this earthquake, only two writers have drawn isoseismal maps. Rothé (1955), from a field visit, assigned intensities, in the Mercalli-Sieberg intensity scale, to many sites in the most affected region and published an isoseismal map (fig. 2). He assigned an intensity I_0 = X (MS) to the epicentral area, a circle of about 12 km radius around Beni Rached,

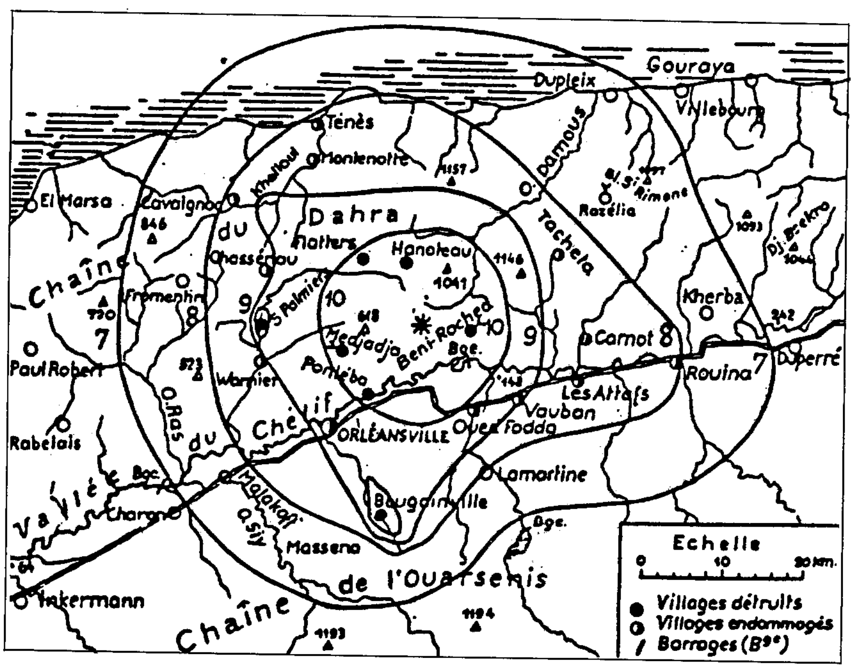

Fig. 2. Isoseismal map (in terms of MS scale) of the main shock of the 9 September 1954 earthquake, after Rothé (1955).

which includes the villages of Flatters, Hanoteau, Ponteba, the douars of Medinet-Medjadja, Beni Rached, Beni Djernine, Tacheta and, out of this zone, the hamlet of Cinq-Palmiers and the village of Bougainville. Ambraseys (1981) has re-evaluated and assigned the following intensities, in the Modified Mercalli intensity scale (MM), to numerous sites in the area affected. He has assigned an intensity I_0 = IX (MM) to Orléansville and Beni Rached; VIII (MM) to Medjadja, Ponteba, Flatters, Hanoteau; VII (MM) to Malakoff, Oued Fodda, Les Attafs, Carnot and VI (MM) to Lamartine (fig. 3). Benhallou (1985), quoting Rothé (1955) and the archives of the Seismological Service in Algeria as his sources, has re-evaluated the intensities in the Modified Mercalli intensity scale (MM), as he mentioned. He has published an isoseismal map of the event (fig. 4) and assigned an intensity I_0 = X (MM) to the most area affected. We remark that neither one of these authors had evaluated the intensity in Spain where the earthquake was reported, by many sources, to be felt in numerous cities. Other writers have assigned intensities only to the epicentral area, Thevenin (1955) gave I_0 = IX-X (MS) to the Beni Rached region, Munuera (1963) gave I_0 = X (MS), Karnik (1969) assigned I_0 = X-XI (MS), ISS and BCIS gave I_0 = XI (MM) and, finally, Ouyed (1981) assigned I_0 = XI (MM).

The first instrumental study of this was conducted, in 1955, at the Bureau Central International de Séismologie (Strasbourg) which gave an epicentral location at 36.283°N, 1.467°E. Other instrumental epicentral locations were given at 36.2°N, 1.6°E (ISS), 36.0°N, 1.5°E (USCGS) and 36.0°N, 2.0°E (USSR).

Magnitudes for this event were also assigned by some authors or stations, M = 6.7 (Rothé, 1955), M_S = 6.5 and m_b = 7.0 (Ambraseys, 1981a), M_S = 6.75 (Pas), M = 6.75-7.0 (Kiruna, Berkeley), M = 6.7 (Pra), M = 6.5-6.75 (Uppsala) and M = 6.5 (Skalnate Pleso).

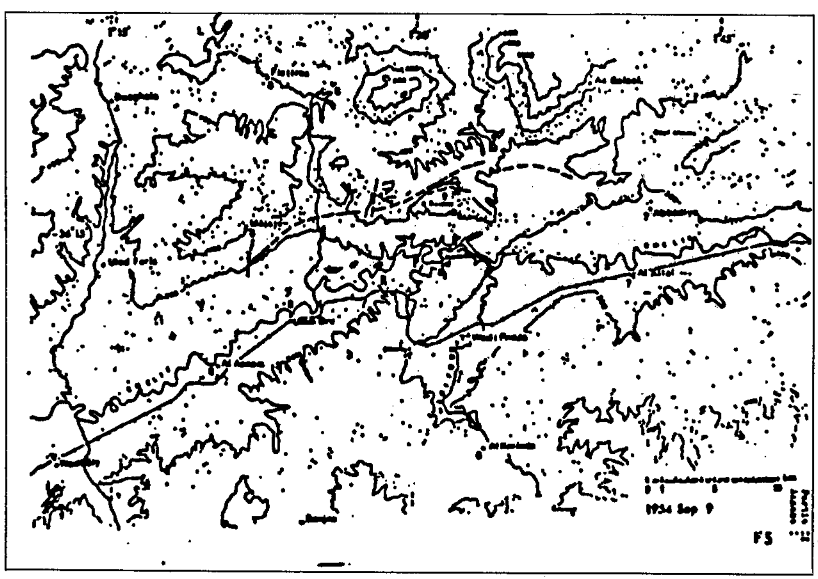

Fig. 3. Intensity distribution (in terms of MM scale) of the main shock of the 9 September 1954 earthquake, after Ambraseys (1981).

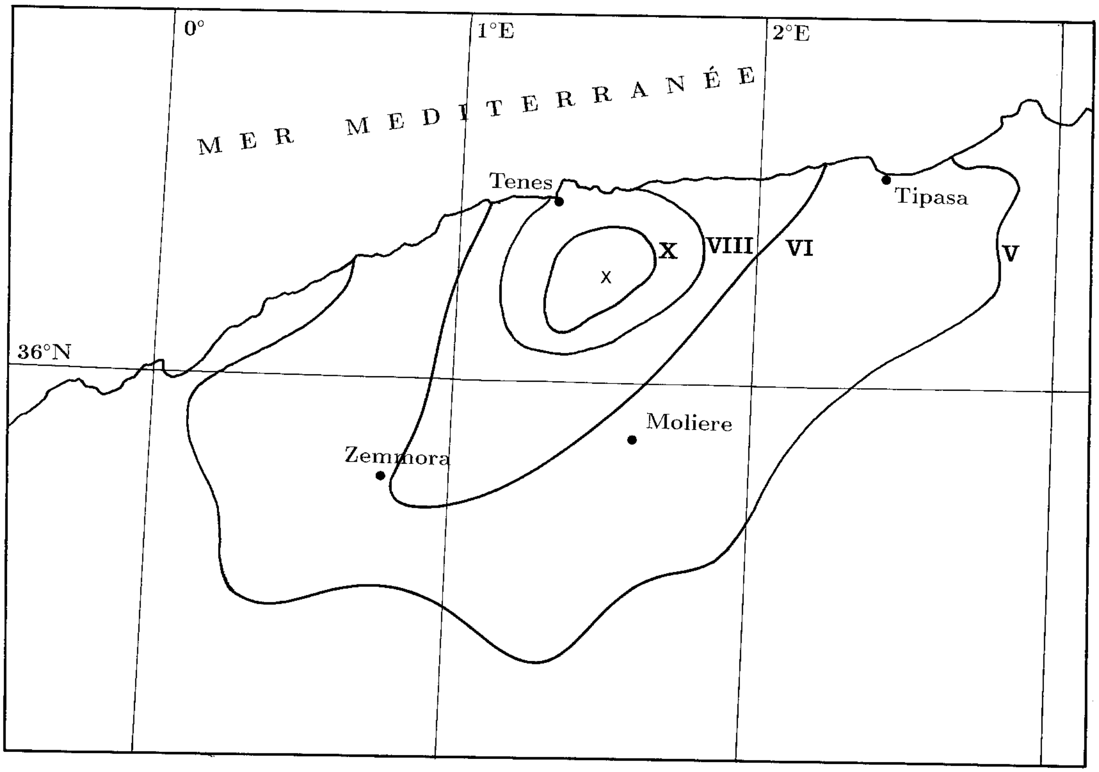

Fig. 4. Isoseismal map (in terms of MM scale) of the main shock of the 9 September 1954 earthquake, after Benhallou (1985). *Redrawn.*

3. Geographical aspects of the epicentral region

The whole region comprised between the two parallel ranges of Dahra and Ouarsenis was devastated by the earthquake. The epicentral area is at about 150 km southwest of the capital Algiers and on the southern side of the coastal range Dahra. The Dahra includes in the north a mountainous region at which the height is over 1000 m, the Djebel (Mount) Bissa culminates at 1157 m, the Djebel Sidi Bernous at 1146 m and the Djebel Tkelout at 1041 m.

Orléansville, a modern city of 32000 inhabitants at the time of the earthquake, the centre of the rich farming region was playing an important role in agricultural trading between Algeria and France. The French settlers, in early colonization times, had chosen the best places to build their farms in terms of soil fertility, topography and communications. If the relatively well built colonization centres were located on the lowest gentle slopes or on the plains where water supply is more abundant, the Algerian native douars were poorly constructed, sparsely distributed in the high plateaux or sometimes dangerously on the abrupt slope of the valley, near small springs which were used for the everyday life and the irrigation of their vegetable gardens. These douars, which are composed of a certain number of gourbis, had a very dense population from 40 to 60 inhabitants per square kilometre. The douars of Beni Rached and Medinet Medjadja, together, counted at that time over 14900 people. Apart the official buildings, the public works and the settlers houses, most native Algerian dwellings were gourbis which experienced total destruction in many parts of the region. The gourbi was a single floor construction, generally built with mud of silty alluvion, mud with local stones or mud with sun dried mud bricks. The gourbi forms a rectangular edifice which could reach 4 to 8 m long and 3 to 4 m wide (frequently 2.50 m wide to 6 m long). It has one small door which constitutes the only opening for the dwelling and sometimes a hole is left in a corner of the roof to let the smoke out. The roof, generally with two inclinations, is constituted with a frame of perches covered of diss (Ampelodesmos tenax) and big stones on top, or simply thatched.

Due to its agricultural vocation the Orléansville region was equipped with an important hydraulic work system comprising dams, pipes, galleries, various types of canalizations, railway line and a good roads network.

4. Damage and casualties distributions

Information provided by various sources were very carefully analyzed before trying to re-assess the damage and the casualties caused by the earthquake. The data available describe quite well the impact of this earthquake on humans, man-made structures and also on the soil itself. Most of the sources give evidence on the destruction of the town Orléansville (if not exaggerated by the press because of its political importance on the continuity of the colonization of the region) and its surroundings.

The area worst hit extends from Orléansville to, 40 km north to its port, Tenes on the Mediterranean Sea and at about 80 km east Miliana. The main shock seriously affected the lower Cheliff Valley and caused widespread destruction, killing about 1409 people, injuring over 5000 others, made homeless more than 50000 and destroyed over 33000 houses and gourbis as reported by the General Government of Algeria.

In Orléansville, the same words were repeated again and again by the population: «... Battlefield scenes, apocalypse, nightmare, etc...», following the violent shaking that was felt early in the dark at 1 h 4 min 37 s (GMT) catching the majority of the inhabitants asleep. Orléansville was devastated, a modern town of 32000 inhabitants, that night looked as through it had been the victim of a thousand-bombing raid. The population was all in a flutter during the shaking. Men, women and children rushed screaming from their beds. They scrambled through the littered streets, trying to get to the open fields. The rupture of the underground gas pipes and electricity cables were thrown up and set fires to furniture and collapsing buildings and houses. The cries of the panicked population, the fires of the devastated buildings, the noise of the crush of falling masonry and the dust in the streets turned the night into a veritable inferno. Wide fissures opened in the streets and homes, some of them big enough to take a car. Some of the fleeing people were engulfed as large cracks opened beneath their feet. As a French estate manager living in Orléansville described the start of the shaking: «... I was awakened by the rumbling which accompanied the first tremor. My house seemed to be spinning and than began rolling like a ship. The lights went out. As we hastily dressed we could hear the crush of falling masonry and...».

The first shock destroyed the town's hospital, prefecture of police, railway station, state prison, the modern college, the military base, the stadium, three hotels and numerous apartment houses. The old cathedral «Saint Reparatus» which dates from Roman times, and a new Roman Catholic church fell in ruins. The modern Baudouin hotel, which was known as «The Pride of Orléansville», was split open by the main shock and where at least forty people died. The most spectacular case of devastation was the nine-storey reinforced building just completed; it was crushed, simply flattened to its foundations and looking as a thick concrete slab. Thirty people were reported bruised under this mass of reinforced concrete. A total of sixty relatively well built reinforced concrete buildings were completely destroyed. It was hard to find a construction unscathed in Orléansville, where ninety percent of the houses were reported damaged, about the third collapsed and, of the remainder, fifty percent had to be condemned. The only site which did not stop receiving the population in the devastated city, in spite the danger it presented, was the Orléansville Mosque which did not collapse.

In the Sous-Prefecture (county) of Orléansville 15000 gourbis were annihilated. All telegraph lines were down, causing an interruption of the communications in the area affected for few days. Around Orléansville, damage was reported to secondary hydraulic works such as elevated canals, galleries and the main pipe system.

If the situation was tragic in Orléansville, it was, however, still less that of the localities around it and particularly in the douars up on the hills. The casualty rates in the colonization villages were relatively low comparing to those of the native Algerian douars in the same zone, particularly the douars of Medinet Medjadja, Beni Derdjine, Tacheta and Beni Rached.

Northeast of Orléansville at about 25 km, the douar of Beni Rached located up on the Dahra mountain was completely destroyed by the main shock. As reported by many sources, the douar was said to be offering hallucinating visions and heart gripping scenes of the population and the gourbis as it was called, after the earthquake, «the country of fear». Most of the native Algerians were living in absolute poverty and isolation on the abrupt sides of the mountainous region. They fled from the lower places for security reasons, believing that higher sites were safer or they had been forced by the French administration, to give up somehow their lands (Yacono, 1955). Seven thousand people living in this douar at that time, all of them native Algerians, were caught asleep in their gourbis. At least 307 people were reported to be found dead under the debris of their homes. The gourbis, in this region, were also built simply by a mixture of mud and straw, sun dried mud bricks or mud with local stones and with a thatched roof surcharged with heavy stones so that it can resist the winds. The gourbis with free weak walls (not tied to each other) and a heavy roof could not withstand the dynamic forces of the earthquake; they were shattered. Many photographs taken after the shaking show the fullness of damage and that just lumps of earth and piles of stones were left on the ground. Numerous sources had described the douar of Beni Rached as vanished. This douar was linked to other villages or douars only by precarious hilly country roads, not accessible by any kind of cars or trucks, which made the relief late and difficult. Three days passed before the rescue teams could reach it. All means to reach it by road after the earthquake had failed. The terrain was presenting an impassability owing the crevasses, rockfall and landslides.

This earthquake had been associated with major soil deformations, particularly, in the Beni Rached region. The shaking was reported to have had dissociated every mamelon of the Dahra mountain. The ground, around Beni Rached and particularly at the site of the «Marabout Sidi Djillali», was hard broken and described as a crack puzzle. The landscape after the shaking had shown two major breaks that caused the formation of a small graben in which the vertical displacement was more than one metre. The col where the Marabout was built subsided about one metre and, naturally, the construction itself collapsed. The surface of the soil presented many other features such as: the formation of real bundles of fissures with significant vertical displacement up to 250 cm, landslides from abrupt versants, rockfall and liquefaction. Some springs of the region dried up, changed their flows or new ones emerged. From the village of Ponteba with 4000 inhabitants, located at 7 km northeast of Orléansville, it was reported that no house nor gourbi was left standing. The railway station was destroyed. Major damage was caused to the hydraulic works between the village of Ponteba and the Ponteba dam which is at about 13 km away. The Ponteba dam, which is 6 km away from the epicentre, was presenting a tilt of 55 cm along 80 m of its length. The tilt motion did take place without provoking any visible dislocation in the masonry but the massive concrete abutments, which were rebuilt in 1952, presented significant cracks, sometimes, of over 10 cm wide. Around the dam, the soil was presenting wide fissurations and particularly the part close to the right bank abutment. The pipes and galleries were smashed in some places and cracked everywhere in the epicentral area. The hydro-electric power plant, at about 4 km of Ponteba village, had its reinforced concrete structure and the filling masonry seriously damaged. In Hanoteau, at about 12 km northwest of Beni Rached, a small important colonization village surrounded by native Algerian gourbis, where about 300 people were living, was completely destroyed. Photographs taken one month after the earthquake show that not an official building, not a house or a gourbi had subsisted. It was reported that in the centre of the village, four facades still standing were hiding behind the fullness of the devastation. Only piles of stones, lumps of earth, timber beams and tiles were littered everywhere and left for observations. There was at least 16 dead. Springs in this village had a higher flow. Nearby, the douar of Beni Derdjine, as the village of Hanoteau, was presenting a frightful landscape. The wretched gourbis, where the poor peasants were living, were reduced simply to lumps of earth, accumulation of stones and perches. East of Beni Rached at about 25 km, the village of Cinq Palmiers was reported to be totally destroyed. The village of Chasseriau, approximately 30 km northeast of Beni Rached, was partially destroyed with the buildings of the gendarmerie seriously damaged. Eleven people were reported to have lost their lives. The colonization village of Flatters, located at about 16 km northwest of Beni Rached, was also reported as completely destroyed. The houses of the Europeans which were of better construction and materials failed to resist the earthquake loads and were destroyed. Even the relatively well built official buildings collapsed, such as the railway station and the post office which were down to the ground. The post office was described as ruins. Seventeen people were reported dead in this village. Most of the farms located between Flatters and Les Heumis were reported destroyed. The springs, up on the mountain, as in Flatters had a higher flow. The villages of Mentenotte and Les Heumis had had many old houses destroyed, the city hall seriously cracked and scores of chimneys collapsed. Cavaignac, at about 30 km northwest of the epicentre, rebuilt after it was completely destroyed by the 25 August 1922 earthquake, had many facades seriously damaged but the reinforced concrete structure did experience no damage. Hardly, a single farmhouse in this stretch was reported to be standing. Tenes, port on the Mediterranean Sea at 40 km north of Orléansville, had suffered heavy damage and casualties, particularly in the Old Arabic Tenes. Many old houses and gourbis collapsed and more other were badly damaged. North and northwest at 40 km offshore of Tenes, several submarine telegraphic cables linking Algeria to Europe were snapped off, on 9 September 1954, between the depths of 2200 to 2500 m. In the «commune mixte» of Tenes, which included many douars, 100 people were reported dead and 20000 others made homeless. The colonization centre of Vauban where 2000 people were living, located at about 10 km southeast of Beni Rached and 24 km east of Orléansville, was reported to be completely destroyed. This village, which is on the down stream of the

Oued Fodda dam, was first razed then flooded by the water escaping from the broken under-pressure pipe linking the dam to the hydro-electric power plant. It was also reported that the hot springs of Vauban had vanished. Nearby at about 10 km east, the village of Les Attafs had experienced heavy damage; the railway station was destroyed. One hundred and thirteen dead in the village of Oued Fodda, located at 20 km east of Orléansville, were found under the ruins of their houses. The railway line between Orléansville and Oued Fodda was seriously damaged, it had experienced distortion and heaving in many places. Also, one bridge was reported to be cracked. The Oued Fodda dam, at about 30 km of the epicentre, did not suffer any damage neither in its elevated structure nor in its foundations; however, the shaking was strongly felt by the dam security guard whose house was seriously damaged. The Portes-de-Fer dam between Oued Fodda and Lamartine did not suffer any damage. The villages of Rouina, located at about 25 km east of Beni Rached, and Carnot at 15 km were hard hit, many casualties and heavy damage were reported. In Carnot, 38 people were found dead under the debris of their houses and the reservoir was presenting cracks in its reinforced concrete structure. At about 15 km south of Orléansville, the colonization village of Bougainville was also reported as totally destroyed, 26 houses over 28 existing at that time were razed to the ground. This village was built on abrupt hillside, on soft soil, which explains the catastrophe experienced. Here also, springs had a higher flow after the earthquake. At the small villages of Dupleix (4 dead) and Rabelais (2 dead), few houses and gourbis were partly destroyed (cracks, fall of plaster...) as well as at the villages of Fromentin, Lamartine, Kherba, Malakoff and Francis Garnier had experienced moderate damage.

Damage extended outside the epicentral region to Miliana about 80 km away east of Orléansville. It was reported that the region of Miliana was badly hit and several hundred people had lost their homes. Three douars in the «commune mixte» of Braz (douars de Tacheta, Chemla et Zougara), and Daira (county) of Miliana, were reported razed to the ground and 118 people died. It was reported by several sources that the population of Algiers was in its majority awakened and people in the high rise buildings panicked. The shaking was also seriously felt at Boufarik, Burdeau, Marengo, Medea, Moliere, Mostaganem, Relizane, Tiaret... etc. It was just felt by the population as far as Tizi Ouzou in the east, Oran in the west and well beyond Tiaret in the south. We have found no evidence that the earthquake was felt in Bougie, Maillot, Sidi Belabbes, Tlemcen.

This earthquake was felt in Spain, not only in Carthagene, Granada and Alicante but also in Ibiza Island and particularly in the Balearic archipelago where the population panicked; however, no damage or casualties were reported.

5. Intensity re-evaluation

Intensities have been re-assessed with reference to the Medvedev-Sponheuer-Karnik – MSK – (1981) intensity scale using both macroseismic and instrumental data provided by a variety of sources. In the whole region affected by this earthquake, it is revealed from various sources that three types of construction existed at that time which may be roughly summarized as reinforced concrete constructions, ordinary brick houses, and adobe and clay houses. Apart from the official buildings, the public works and very few settler houses which were built with reinforced concrete structure filled with masonry (classified in type C according to the MSK scale), most settler houses and very few native Algerian houses were built with ordinary brick (type B, MSK) and, finally, all the remaining native population houses, or gourbis as described earlier, were adobe or clay constructions (type A, MSK). Typically, the traditional Algerian gourbis are very vulnerable constructions. A large number of these constructions, according to the Algerian history, were seriously damaged or totally destroyed by downpour which give a proof of their inherent weakness. Even official buildings and newly built constructions as hotels and apartment blocks, built with reinforced concrete, had shown little extra resistance. As a matter of fact, the introduction of new materials in the absence of a proper building regulations had made a new type of vulnerable structures.

As a consequence of the defectiveness of the gourbis, most popular rural housing at that time, maximum intensity in any destructive earthquake in the douars appears to be effectively the same. That is, at intensity IX on the MSK scale, most of the gourbis are totally destroyed and any douar would thus appear equally, but not more, devastated at higher intensities of the scale. Thus, higher intensities, in many rural parts of Algeria, can only be re-evaluated from the behaviour of official buildings, public work constructions and other relatively well built reinforced structures.

After much analysis, maximum intensity was re-estimated at X and was assigned to a number of colonization villages, douars and some hydraulic works sites which suffered serious damage described above. The sites which are believed to have experienced most damage are Orléansville, Beni Rached, Ponteba, the Ponteba dam, Hanoteau, douar Beni Derdjine, Medjadja, Cinq Palmiers and Flatters. Intensity IX was assigned to Oued Fodda, Vauban, Warnier, Bougainville, Chasseriau and douar Tacheta. Broadly, intensities IX-X were assigned within the zone that contains reinforced concrete structures and masonry constructions seriously damaged or destroyed, gourbis totally destroyed, high casualty rates, public works damaged and major soil deformations associated with the earthquake. Intensity VII was assigned to Mentenotte, Les Heumis, Tenes, Les Attafs, Rouina, Khalloul and Carnot. This intensity was generally assigned to destroyed douars, damaged reinforced concrete and masonry structures. Intensity VII was assigned to Dupleix, Rabelais, Fromentin, Lamartine, Kherba, Malakoff, Francis Garnier and Oued Fodda dam. This intensity was assigned to partly or destroyed douars and slightly damaged reinforced structures. Intensity V was assigned to Algiers, Boufarik, Burdeau, Marengo, Medea, Moliere, Mostaganem, Relizane, Tiaret and the Balearic Archipelago. Intensities IV-V were assigned, mainly, on the basis of awakening of most of the population and panic of the people living in high rise buildings. Intensity II-III were assigned to Aumale, Tizi Ouzou, Oran in Algeria, and Granada, Alicante, Carthagene and Ibiza Island in Spain. Low intensities II-III were re-estimated solely on felt effects reported by the sources of information available. The details of the re-assessed intensities equal or greater than VII (MSK) in the area affected are given in fig. 5. Figure 6 shows the isoseismals drawn for the 9 September 1954 earthquake (main shock) for the felt region.

6. Magnitude determination

The surface-wave magnitude of the earthquake was determined from the standard Prague formula (Vanek *et al.*, 1962), using teleseismic amplitude and period readings from 17 stations located at distances between 5° and 160°, and a preliminary epicentre at 36.31°N, 1.47°E (macroseismic epicentre). The data are presented in Benouar (1993). The mean period is 13.5 s and the derived value of M_S, without station corrections, is 6.7 ($\pm$ 0.2). As for the main shock, the surface-wave magnitude for the strongest aftershock, which occurred on the 10th of September 1954 at 5 h 45 min, was calculated, using teleseismic amplitude and period readings from 12 stations located at distances between 5° and 155°, and a preliminary epicentre at 36.6°N, 1.3°E (BCIS). The data are shown in Benouar (1993). The mean period is 11.2 s and the derived value of M_S, without station corrections, is 6.3 ($\pm$ 0.35).

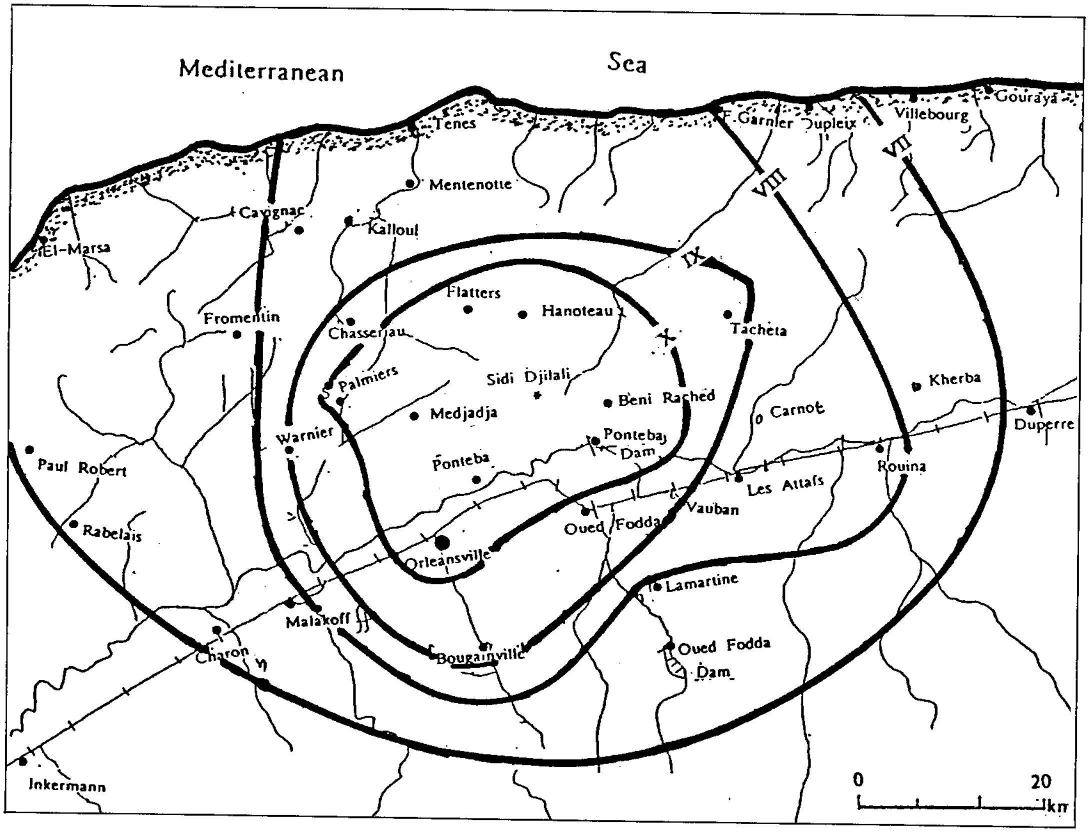

Fig. 5. Isoseismal map for the re-assessed intensities VII$^+$ (MSK scale) of the main shock of the 9 September 1954 earthquake for the area most affected. The star shows the macroseismic epicentre.

7. Foreshocks and aftershocks

It apparently seems that the main shock occurred without a foreshock. In the other hand, it was followed by a long sequence of aftershocks of less energy and continuing until late December 1954. Over 350 aftershocks had been felt or recorded during this period. In the 24 hours following the earthquake, the Institut de Physique du Globe d'Alger (IPGA) had recorded 69 shakings which 54 were very light. The continuity of shaking created, in the epicentral region, a sensation of insecurity which seriously undermined the spirits of the population and made them fearing another disaster. The most important aftershocks occurred on the 9, 10 and 16 September 1954, the 12, 19 and 21 October 1954 and the 12 November 1954. Only the following aftershocks which caused significant damage had had some of their characteristics determined. The 9 September 1954 occurred at 9 h 32 min (GMT) for which was assigned a magnitude as M = 5-5.25 (PRA) and M = 6 (UPP) and an epicentral location at 36.2°N, 1.6°E (ISS), 36.283°N, 1.467°E (BCIS), and 36.0°N, 1.5°E (USCGS). The 10 September 1954 occurred the largest aftershock at 5 h 45 min with a duration of

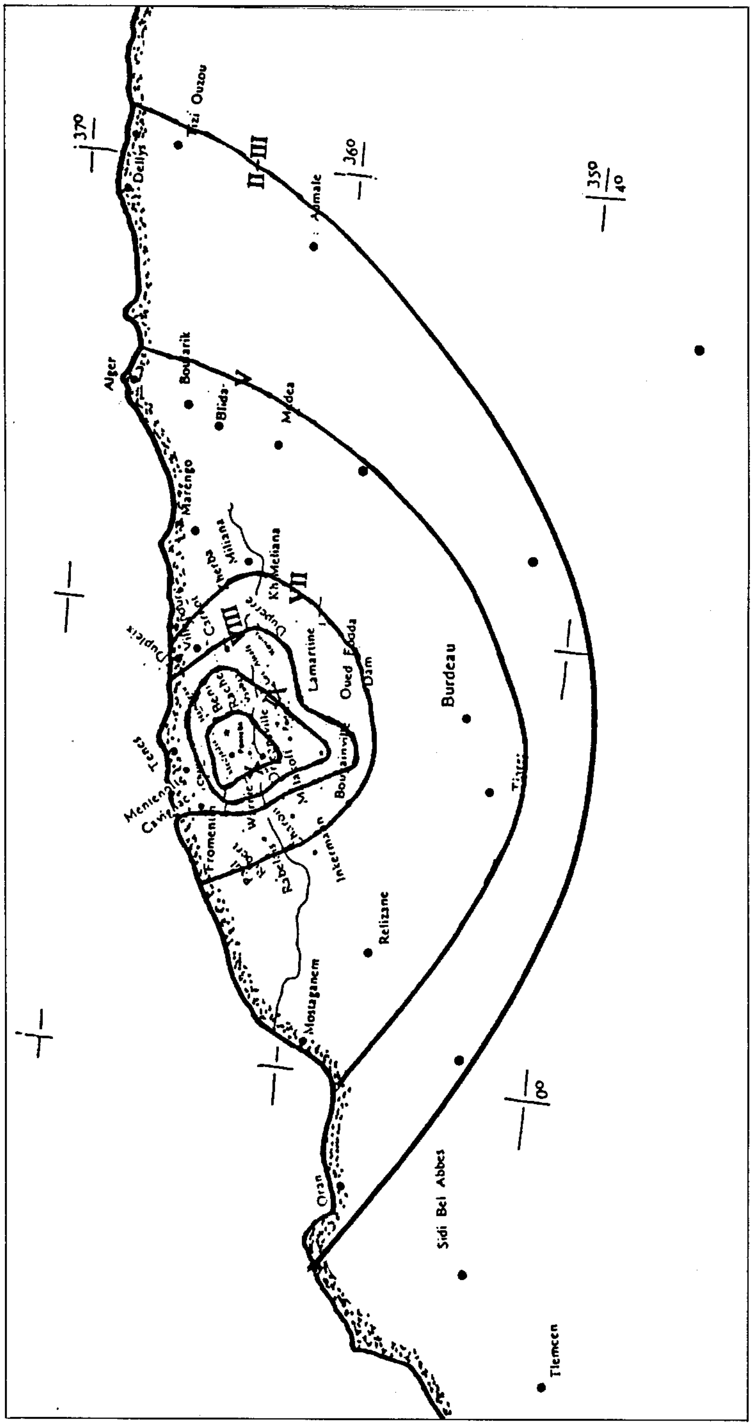

Fig. 6. Isoseismal map for the re-evaluated intensities (MSK scale) of the main shock of the 9 September 1954 earthquake for the felt region. The star shows the macroseismic epicentre.

6 s which was strongly felt at Mentenotte, Cap Tenes, Cavaignac, Dupleix, particularly in Tenes and well beyond Algiers (Rothé, 1955). Ambraseys (1981a) assigned intensities to some sites damaged by this aftershock. The shock was widely recorded and do allow a surface-wave magnitude determination, the details of the data are given in Benouar (1993), that gives M_S = 6.3 (± 0.35). Few agencies and seismological stations had also assigned magnitude: M = 6.2 (PRA), M = 6.0 (UPP), M = 6.25 (KIR), m_b = 6.7 (Mezcua and Martinez, 1983) and an epicentral location at 36.6°N, 1.3°E (BCIS), 36.0°N, 2.0°E (USCGS), 36.01°N, 1.48°E (Mezcua and Martinez, 1983) and 36.5°N, 1.2°E (ISS). This aftershock had particularly affected the region of Tenes where constructions, already half in ruins after the earlier tremors, crumpled into the masses of rubble adding further to the huge death-roll.

The aftershock of 16 September 1954 at 22 h 18 min, which caused heavy damage to the already weakened buildings in Orléansville, was widely felt at Attafs, Ammi Moussa, Carnot, Montenotte, Tenes, Tiaret and was located on the same site as the main shock (BCIS).

8. Discussion

The whole region included between the ranges of Dahra and Ouarsenis which separate the Cheliff Valley was ravaged by this earthquake. The region affected is well known to be a rich farming area and Orléansville an important agricultural trading centre. Except the colonization centres such as Orléansville, Ponteba, Flatters, Hanoteau and other villages which were destroyed to a high proportion, the large number of victims were found not in these settler sites but in the douars, very densely inhabited (40-60 people by square km), where the gourbis were poorly built. The constructions exposed to this earthquake were of three types: the gourbi or adobe house which constituted the 3/4 of the housing, the ordinary masonry farmhouses of the settlers and the reinforced concrete structures such as hotels, high rise flat blocks, official buildings, and public and hydraulic works.

The knowledge of the historical, socio-economic situations, demographic conditions, cultural, and religious background and the characteristics of the constructions is fundamental for a better re-assessment of the damage. Since the end of World War Two to the year of the earthquake and after the massive killing in 1945, by the french army, of native Algerians who were asking for independence, Algeria entered into a very politically instable phase described by discrimination and repression. The year of the earthquake, 1954, and about two months later, on November 1st, the native Algerians launched the armed revolution which ended by the recovery of independence in 1962. Particularly during the period before the earthquake, we believe that most of the information were reported as to show security and stability to the French settlers and to hide the continuous growing dissatisfaction among the natives. For instance, the General Government of Algeria reported by its official information means that the earthquake had killed 1409 people (including only 40 Europeans), injured more than 5000 others and left over 50000 homeless. Other Government independent sources reported that more than 15000 were injured, 18000 houses and 35000 gourbis destroyed, and made 300000 homeless in the whole region affected. The French administration was making discrimination between the cities and the douars and between the elements of the population, of course, at the expenses of the natives. It was also reported that many natives had buried their deaths without declaring them to the French administration. Then the figures of casualty and damage, officially communicated, are given fairly as indication and must be taken with care. Even for the damage reported by various sources, one should be aware of the language, the commercial side of the newspaper and sometimes the involuntarily communicated information which could be not exact. For instance for this earthquake, in one account, it is said that: «... the small Lamartine and the large Oued Fodda dams were cracked and they caused flooding in several hundreds of acres; water pouring from cracked dams swept one village in which two hundred people are believed to have been drown. In the afternoon, the water from the broken dams began encroaching the airport, interfering with the evacuation of the wounded...». Analyzing some documents of scientific study on the effects of the earthquake on hydraulic works (Thevenin, 1955) and other press reports, we did not find any mention to these facts; however, they reported damage to Ponteba dam, flooding, not as serious as reported by the press earlier. The flooding was due to the smashed pipes and galleries and these reports indicated that Oued Fodda and Lamartine dams did not suffer from the earthquake. Always for a better re-assessment of the damage caused at that time, one should be very careful in analyzing more than one source to avoid gross errors.

Although, the damage was reported as due to the main shock of the 9 September 1954 earthquake, the possibility of cumulative damage remains from the earlier strong aftershocks and particularly from the largest one which occurred on 10 September 1954.

Summarizing the results, we obtain the following final data for the 9 September 1954 earthquake: origin time (GMT) 1 h 4 min 37 s; instrumental epicentre at 36.283°N, 1.467°E; macroseismic epicentre at 36.31°N, 1.47°E; focal depth of about 10 km; magnitude M_S = 6.7 (± 0.2).