
Chapter III

Case histories

1. Selection criteria

This chapter presents brief descriptions not only of the most important from the human point of view, but also the most informative earthquakes to have occurred in the Maghreb region during the twentieth century. The investigations of these events are based on both macroseismic and instrumental data collected from a variety of source documentary materials discussed in the previous two chapters. The concise description of each selected event states the most important information available and an analysis of this according to the specific historical circumstances already examined. Detailed studies of these earthquakes have been achieved in this study and are presented in Appendix B. This sample of earthquakes, which is considered as a representative selection in the Maghreb, depicts most of the difficulties connected with inquiring into the twentieth century seismicity of this part of the world. It also gives a good picture of a specific pattern relative to the spread of damage, human behaviour and ground deformations in the region under study. However, in terms of seismic hazard and risk evaluations, these events are of the greatest interest. A quantitative analysis of these earthquakes is included in the Maghreb earthquake catalogue in which are tabulated all the events to have occurred this century and identified in this study. Some earthquakes reported in the catalogue, as large as those presented in case histories, have not, for different reasons, been studied in detail. In addition to

the individual destructiveness of the earthquakes, the availability, the quality and the completeness of the data constitute a prime necessity for a full study of the event. Likewise, some events are omitted when the macroseismic data or accounts relative to them do not bring any new knowledge or improvement to any aspects of specific interest, or when they occurred in areas which are already well studied in association with other, more informative, earthquakes. Although they are left out from case histories, nevertheless an extensive search in source documents relative to these earthquakes has been made as well as their instrumental data analysis.

For each event presented in this chapter, an isoseismal map has been constructed according to the quality and completeness of the original data available (see Appendix B). These maps illustrate localities in the felt area for which detailed macroseismic information exists and an assessment has been carried out, as well as the extent of damage and macroseismic epicentres. Names of cities, villages and douars are those employed at the time of the earthquake and not those used today.

Other specific issues of interest which are directly related to earthquake occurrences are also described in this chapter.

2. Case histories

The most illustrative earthquakes of the seismicity of the Maghreb region during this century are briefly described below.

2.1. 1903, September 23; Boghari

$$M_S = 5.50 (\pm 0.15), I_0 = VII$$

A destructive earthquake in the region comprised between Boghari, Boghar and Moudjebeur, in the same region which experienced many damaging seismic events in the last two centuries. Most damage, which consisted of collapse of numerous local traditional houses, was observed in Moudjebeur and its immediate vicinity. In Boghari and Boghar, damage was not more serious than cracks in ceilings in scores of houses and broken window panes, but the shaking did cause a great panic among the population. Slight damage to old buildings and considerable concern among the inhabitants was reported in Chebli, Blida, Affreville and Bou Medfaa, and fissures in walls of the hospital and panic in Douera. In Medea, Lodi and Miliana, as well as in Boufarik, people run outdoors. In some quarters of the capital Alger, Hussein dey and Maison Carrée, there was some serious concern but no panic or damage. It awoke people in Arba and Rovigo, but here few people rushed outdoors. The shaking was slightly felt as far east as Theniet El Had and west as Aumale. No evidence was found in reports about any sightings of ground deformations. Two items of hydrological information were given; in Moudjebeur, the flow of a spring increased four-fold and in the hot spring Spa of Hammam Righa, the temperature rose by 2°C.

The main shock was preceded by two small foreshocks and followed by a slight aftershock felt at Blida.

The analysis of the macroseismic data collected has improved considerably the accurate location of the epicentral zone.

2.2. 1908, August 4; Constantine

$$M_S = 5.25 (\pm 0.10), I_0 = VIII$$

A damaging earthquake struck the town of Constantine and its surrounding villages and douars. The main shock, which lasted about 10 s, and its aftershocks caused the

loss of about 12 lives, injuring several and destroying numerous houses, farms and important buildings. It caused severe damage, particularly, to the civil and military hospitals, the Lycee, the cathedral, the theatre, the covered market, the military club, the school house, the Zouave barracks, numerous old buildings and particularly local traditional houses in Constantine. Several sections of walls were crushed down in the quarter of the town called «Quartier des Chasseurs d'Afrique». Scores of old houses and schools were destroyed in Sidi Mabrouk. Many douars around Constantine were reported to be in ruins. In the Faubourg Saint-Jean and El Kantara, many ceilings and walls collapsed and scores of facades of houses were seriously cracked. Considerable damage was sustained by surrounding farms in Rouffach and Conde Smendou. In El Arrouch, the shock was so strong that the population run outdoors and fissures were caused in walls at the hospice buildings. Local houses were reported completely destroyed in the Ksar El Kellel. There was a general panic but no damage in Phillipeville, Bône, Souk Ahras and La Calle (175 km distant). In Guelma, Ain Smara and Mila, as well as in many other centres of the Constantine Department, considerable shock was felt but no alarm or damage occurred. The cost of damage was estimated, by the French administration, at 400000 French Francs.

The earthquake was associated with a 200 m long and 50 cm wide ground surface fissure which was observed in the Plateau of Mansourah. All springs, usually cold, became suddenly hot and the thermal springs changed colour to blood-red which caused fear and panic to the native population.

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 main shock was recorded in many seismological stations, up to Tiflis (U.R.S.S.) and Helwan (Egypt).

2.3. 1910, June 24; Aumale

$$M_S = 6.60 (\pm 0.3), I_0 = VIII$$

This represents the strongest felt and recorded seismic event in Aumale region. This event is the third largest shock in Algeria this century, after 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 numerous traditional local dwellings, colonial houses and public buildings in the affected area. The earthquake was widely felt in Algeria; 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. No indication of ground deformation was found in any report, except a massive rockfall along the road between Aumale and Masqueray and small fissures in a vineyard in Chera-gas. The earthquake occurred without a foreshock, but was followed by a long series of aftershocks, continuing until January 1911, with one strong enough to cause more damage. The main shock was recorded by almost all the seismological stations operating at that time. The instrumental epicentre was relocated at 36.3°N, 3.7°E which is in good agreement with the macroseismic epicentre (this study) at 36.23°N, 3.43°E. The source documentary materials available today give evidence of the destruction in the region comprised 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. About 30 people were killed in Ouled Dahmane, 12 in El Arba, 12 in Douar El Euch and 27 at Ouled Meriem (previously destroyed in 1886), a region in the vicinity of Souk El Arba.

An improvement of the delimitation of

the epicentral zone has been achieved by adding macroseismic information newly retrieved from contemporary sources, but the lack of reports from the eastern part of the country or from the south prevented the construction of a complete isoseismal map of the event.

2.4. 1922, August 25; Cavaignac

$$M_S = 5.10 (\pm 0.30), I_0 = VIII$$

At lunch time, with no premonitory sign, a destructive earthquake in the Orléansville-Ténès region destroyed the colonization village of Cavaignac. A series of aftershocks followed the earthquake, with one strong enough to add to the damage. The main shock, which lasted about 15 s, caused the loss of 4 lives, injured a few and made hundreds homeless. The number of victims was reduced by the fact that almost all the inhabitants were having lunch in their gardens or in the open in the surrounding farms. The shaking was felt over a distance of 270 km from Alger in the east to Relizane in the west of Cavaignac.

Of over 50 houses existing at that time in Cavaignac, 40 were completely destroyed and none of those remaining was suitable for use. Official buildings, relatively better built, sustained damage which consisted mainly of fissures in exterior walls, but their interiors were devastated: partition walls, plaster, glass, ceilings and parts of roofs were jumbled together with all the furniture. Local traditional dwellings in Talassa, Kalloul, Mentenotte, Flatters, Ténès, Hanoteau, Chasseriau and Fromentin experienced total destruction and/or heavy damage whereas the colonial structures sustained only cracks in walls and some destructions of roofs and free-standing walls. In all these sites, there was a general panic and people fled their homes, but no casualties were reported. In Charchell, damage was insignificant but the shock provoked some anxiety among the population. No damage was observed in Orléansville, Warnier and their surroundings but the

shock was seriously felt. It was slightly perceived by a few people in Alger and Relizane. Soil deformations were not major, only a few cracks were reported in the northern part of Cavaignac and rockfalls in the eastern part. On the other hand, hydrological effects were significant; the flows of the springs in the epicentral zone increased by up to five times, water flowed in ravines which were previously dry and water levels in wells and oueds rose by up to 30 cm.

Additional macroseismic information retrieved from different sources has allowed a better assessment of the effects of this event and the construction of an isoseismal map of the main shock.

2.5. 1924, March 16; Mac-Mahon

$M_S = 5.35 (\pm 0.33)$, $I_0 = VIII$

A damaging earthquake struck the southwest region of Batna in the oriental limits of the Saharan Atlas. It centred in the area comprised between the Aures Massif, Djebel Metlili and the Belezma Mounts. The earthquake occurred without any premonitory sign but was followed by three slightly felt aftershocks. The main shock, which lasted 8 s, caused the loss of 4 lives, injured several and rendered many homeless; it destroyed and/or heavily damaged many local traditional houses, colonial structures as well as public buildings. Most damage was found in the zone containing Batna, Mac-Mahon, Douar El Ksour, Arris and Victor Duruy. Total destruction of the local traditional buildings and loss of life were reported in the Douar El Ksour. The shaking was particularly violent in Mac-Mahon where the Bordj of the city was so seriously damaged that it had to be evacuated, but there were no casualties or injuries among the population. Also in Victor Duruy, Arris and Batna, the shock, which destroyed scores of native people's traditional dwellings, caused total panic but no casualties. Colonial structures sustained only minor damage. The shaking was seriously felt in El Kantara, Bernelle, Barika, N'Gaous

and their surroundings, where it caused some concern among the inhabitants. There was no evidence of any sign of ground deformations or liquefaction. The affected zone was a sparsely populated region; many douars scattered in different valleys and surrounding mountains were not mentioned in any report.

The revision of instrumental and macroseismic information has allowed a better and more detailed re-assessment of the impact of this event. The new relocation of the instrumental epicentre (35.4°N , 5.8°E) is found to agree well with the determined macroseismic epicentre (35.42°N , 5.90°E).

2.6. 1924, November 5; Ben Chabane

$M_S = 4.80 (\pm 0.08)$, $I_0 = VIII$

This earthquake occurred near to where early destructive shocks had caused major damage. The main shock, which lasted 15 s, caused the loss of lives, injured several and rendered many homeless. Scores of gourbis, colonial houses and farms were destroyed or seriously damaged. Most of the damage was observed in the area comprising Ben Chabane, Saint-Charles, Sainte-Amelie and their close surroundings. The shaking was felt as far east as Fort National, south to Boghari and west beyond ChercHELL. The earthquake occurred without any foreshock but was followed by a series of aftershocks, continuing up to early 1925. In Ben Chabane as in Sainte-Amelie, Les Quatres Chemins and Saint-Charles, the damage consisted of the destruction of numerous local traditional dwellings and farm buildings, and the fall of scores of chimneys and roofs. The shaking caused general panic among the inhabitants who fled to the open. Damage in Boufarik was mainly, except for the destruction of a few poorly built dwellings, severe fissures in exterior and partition walls, fall of plaster, loosening of walls and the overthrow of scores of chimneys. The earthquake was strongly felt at Zeralda, Staoueli, Saoula, Fouka and Tipaza where it caused cracks in

walls and ceilings in many places and considerable concern among the population, but no serious damage. It was clearly felt indoors by many people in Beni Amrane, Rouiba, Ain Taya, Isserville and their close surroundings.

Substantial decrease of the flow in different springs was reported in the epicentral area. In Les Quatres Chemins, the earthquake had broken a water pipe and produced a large ground surface fissure. No evidence of any sign of liquefaction was found.

The review of the contemporary sources relative to this event has given more details concerning the epicentral zone as well as the relocation of instrumental and macroseismic epicentres.

2.7. 1928, August 24; Inkermann

$$M_S = 5.40 (\pm 0.22), I_0 = VIII$$

Preceded by a slight foreshock two minutes earlier, an earthquake struck the Cheliff Valley and caused significant damage and loss of life in Inkermann and its immediate vicinity. The main shock caused the loss of 4 lives (natives), injuring a few and making numerous people homeless. In Inkermann, most damage consisted of collapse of local traditional dwellings and cracks or fall of sections of walls in colonial buildings. The same degree of shaking was experienced at Sainte-Aimé where newly built buildings, as well as gourbis, collapsed totally. Significant damage was reported in Hamadena, but details are missing. The shaking was strong enough to cause considerable panic in Inkermann, Sainte-Aimé and in douar Hamadena where people had fled their homes. In Relizane, the shock, which lasted 13 s, caused slight fissures in walls of shops and houses. The buildings and the church steeple were seriously shaken but no significant damage was reported. There was some concern among the inhabitants, but no serious alarm. Only few objects were reported broken in the city of Orléansville. In Mongolfier and Perregaux,

the earthquake had considerably shaken the structures, but no damage was observed. The shocking was clearly felt in Mascara, Tiaret, Blida, Mostaganem and Boghari 160 km distant from the epicentre.

The main shock was followed by three slight aftershocks, it was recorded by 72 seismological stations, up to Irkoutsk 71° away. One particular phenomenon, which was left behind by the earthquake on the right bank of River Cheliff, is the spouting of several springs, of which some were petroliferous.

2.8. 1934, September 7; Carnot

$$M_S = 5.10 (\pm 0.20), I_0 = VII$$

A destructive earthquake before dawn caused important damage to the colonial village of Carnot in the Cheliff Valley. This earthquake did not occasion any loss of life, but eleven were injured by the fall of bricks or stones and roofs. The main shock was preceded by a small foreshock and followed by a series of aftershocks of which one was strong enough to add to the damage. The main shock was reported to the ISS by 48 seismological stations. The shaking was felt in the whole region containing Alger and Zemmora (225 km distant), and the coast and Tiaret (130 km). In Carnot, the main shock, which lasted 13 s, affected all the buildings and caused total panic among the inhabitants who fled their houses. The worst damage was observed in the native douars where structures of adobe type (gourbi) collapsed. Only damage such as cracks in walls and the collapse of scores of chimneys and ceilings was reported in many colonial constructions. The water reservoir in the north of Carnot did not suffer any damage. Electric cables were cut. Also, in Saint-Cyprien, some local traditional houses were completely destroyed and the rest significantly damaged. Most of the damage in the hospital, school and post office was no more serious than cracks in walls and floors, collapse of chimneys and

ceilings, and the fall of bricks. The shaking caused considerable panic among the population. In Les Attafs, the old houses and goubis were seriously damaged. Public buildings such as the post office, the gendarmerie and the Docks co-operative sustained slight damage. Also many free-standing walls and cornices collapsed and most of the objects on shelves were thrown to the ground. The inhabitants of Kherba, Duperré, La Ferme, Hanoteau, Flatters and Tacheta were so frightened that they fled to the open. These localities suffered only minor damage and no casualties among the population. Elsewhere the earthquake was slightly perceived.

The water in the region of Carnot showed a white colour in some places and muddiness in others during few days after the shaking. Modifications in the water table level were also reported. The earthquake triggered a number of landslides and rockfalls in the surrounding mountains and caused slumping in the plain. At Carnot cemetery, the soil was seriously fissured, graves were raised and, at about 500 m away, a large crevasse of 200 m long, 2 m wide in some places and 1.75 m deep was produced.

The re-examination of later reports, together with the new information inferred from the source documentary materials relative to this event shows that its impact has been over-stated.

2.9. 1937, February 10; Guelma $M_S = 5.20 (\pm 0.22)$, $I_0 = VIII$

Preceded by a local foreshock, a destructive earthquake struck the Basin of Guelma, destroyed Lapaine and Bled Gaffar and severely damaged other nearby towns, villages and douars. It caused the destruction of numerous local traditional houses, colonial structures and farms as well as public buildings. This shock occurred very near to where early damaging events in 1908 and 1928 had seriously affected the same epicentral area. The main

shock was felt in the whole northeastern part of Constantine Department, up to Tabarca in Tunisia 150 km distant. It was reported to the ISS by 48 seismological stations. The earthquake was followed by many aftershocks with one of comparable magnitude, which added to the damage. In Guelma, most of the structures were affected; the worst damage was experienced by the Royal Hotel and the apartment buildings. Also the city hall, the schools, the mosque, the theatre and the prison sustained heavy damage. The shaking caused a general panic among the inhabitants, who rushed outdoors. In Lapaine, most of the buildings, mainly adobe dwellings, were razed to the ground and 2 people lost their lives, 16 were injured and 28 families were rendered homeless. In Bled Gaffar, almost all the buildings sustained some damage such as cracks in walls, crash down of partitions, collapse of chimneys and roofs for the colonial structures. The goubis were completely shattered. In the epicentral zone, farms suffered heavy damage and destruction, as shown in photographs taken shortly after the earthquake. In Gounod, several housing units were destroyed but there were no casualties among the population. Significant damage was also observed in Petit, Laverdure, Millesimo, Hammam Meskhoutine and Heliopolis. Damage no more serious than cracks in walls was observed in Zarouria, Souk Ahras, Duvivier, Fauvelle, Barral, Bone, Ain Mokra, etc.; the shock caused some concern among the population. The shaking was strongly felt in Phillipeville, Saint-Charles, El Arrouch, Herbillon, Le Tarf, etc., but no damage was reported. No information relative to this event was found from the southern part of the country.

The earthquake was associated with rockfalls and ground surface cracks in douar Khezara, slight landslips and slumping, but no sign of liquefaction was found. It affected the flows of all the springs of the Basin, particularly those of the hot springs Spa of Hammam Meskhoutine, which increased considerably.

2.10. 1943, April 16; Mansoura

$$M_S = 5.30 (\pm 0.04), I_0 = VIII$$

A damaging earthquake shook the Bibans ranges in the central part of the Tell Atlas, particularly the western region of Bordj Bou Arreridj. The shock centred in the zone comprising the Bibans, Portes-de-Fer, Medjana and Mansoura where most damage was reported. The main shock caused the loss of at least 9 lives, injured 11 and made more than 1000 homeless; it destroyed or badly damaged about 250 local traditional dwellings and slightly affected the colonial structures. The radius of perceptibility was relatively small, the shaking being felt in the area limited by Bouira, El Kseur, Tixter and Cerez as well as in Ain M'lila 180 km away. The earthquake occurred with one foreshock, but it was followed by a series of aftershocks, continuing until September 1943. The main shock was reported to the ISS by 44 seismological stations, it was recorded up to Pasadena (U.S.A.) 92° away. In douar M'Zita, the main shock caused the loss of 3 lives, injured 9 and rendered about 900 homeless; it ruined 30 gourbis and severely damaged 150 others. In Mansoura, at least 21 gourbis were destroyed and many more damaged, the tower top of the gendarmerie barracks was overthrown and European structures sustained serious cracks. In Mansoura-Kebira, Mansoura-Seghira, Medjana, El Achir and Dar Beida, much of the damage consisted of the destruction of adobe houses and the fall of chimneys. Slight damage was observed in some structures in Bordj Bou Arreridj. Along the Alger-Constantine railway, a train station had its walls dislocated and four bridges had their abutments cracked and parapets overturned. The forest house in Arbea-Arboul was razed to the ground.

The earthquake triggered significant rockfalls in Djebel Mansoura. The flow of the spring in douar Ouled Aicha decreased substantially. Also many springs in the epicentral zone dried up after the shaking.

2.11. 1946, February 12; Berhoum

$$M_S = 5.55 (\pm 0.17), I_0 = VIII$$

A catastrophic earthquake hit the Hodna plain, seriously affecting a relatively small area at the junction of four districts: Maadid, Rirha, Barika and M'Sila. Most damage was observed at the douars of Ouled Addi Guebala, Berhoum and Ouitlem. In the southwest of Constantine region, over an axis of about 100 km, all the villages and particularly the douars were more or less affected by the shaking, but it was the douar Berhoum and its surroundings that suffered most. The main shock caused the loss of at least 277 lives, injured about 118 and rendered approximately 7500 homeless; it destroyed and/or heavily damaged about 1000 housing units in 10 douars. Also around 576 sheep and goats, 23 horses, mules and bovines, and 14 donkeys were reported killed. The earthquake was felt as far north as Bougie, west as Boghari, south as Tolga and east as Ain M'lila, an area of about 70000 square kilometres. In the district of M'Sila, at least 62 people were killed, several injured and 539 dwellings completely destroyed, making about 3200 homeless. At the district of Maadid, the shock caused the loss of 79 lives, injuring many and making about 1200 homeless; it destroyed at least 177 local traditional housing units. In the district of Barika, 123 people perished, several were injured, 129 dwellings were totally destroyed and 139 heavily damaged, leaving about 1800 homeless. Also at the district of Rirha, where 13 people were reported killed and 11 injured, the earthquake completely destroyed 38 gourbis, rendering about 250 homeless. The shaking was seriously felt by many people at Biskra, Boussaada, Beni Iman and Melouza, but no casualties nor damage were declared.

The earthquake was associated with massive rockfalls and landslides which obstructed the roads between Setif and Magra, and between Colbert and Barika. The national road 28 was closed to traffic at the gorges of Soubella due to landslides and rockfalls.

It is noteworthy that the epicentral region experienced, days before the earthquake, a heavy downpour of rain which certainly affected the local traditional houses.

Although it is unusual that a shock of this size is not followed by any additional shock, no evidence of any foreshock or aftershock was found. The main shock was reported to the ISS by 91 seismological stations and was recorded up to Pasadena (U.S.A.) 93° distant.

2.12. 1947, August 6; Constantine

$$M_S = 5.00 (\pm 0.29), I_0 = VIII$$

Preceded by two slight shocks twelve hours earlier, a damaging earthquake struck the city of Constantine and its surroundings. The main shock, which lasted between 6 and 8 s, caused the loss of three lives, injuring several and making scores homeless; it destroyed numerous local traditional houses and farms in the epicentral zone. The shaking was felt in a relatively small area, as far east as Medjaz Amar, west as Fedj M'Zala, south as Ain Fakroun and north as the coast.

In Oued Hamimine, which is believed to be the epicentre, several buildings collapsed, trapping their inhabitants or livestock under the rubble, but it was the farms that suffered most. More than twenty farms were totally destroyed and twenty others were heavily damaged in the region. In the city of Constantine the shock, which caused general panic among the population, inflicted serious damage to numerous old constructions. Most damage consisted of cracks in walls, fall of chimneys, roofs and ceilings; the modern reinforced concrete structures and ashlar buildings did not suffer any damage. At Ain Smara, several walls were seriously cracked, tiles removed and crashed to the ground, dishes and glassware were broken, furniture overturned and small bells rang. Also in Rouf-fach, Conde Smendou, Guettar El Aich and Ain El Abid, damage was not more se-

rious than a few fissures in walls and the fall of ceilings. Only fine cracks were observed in Oued Athmania, Belfort, Graram, Ouled Rahmoun and Bou Malek. There was some concern among the inhabitants, but no alarm, at Ain El Arab, Mejez Amar, El Guerrah, Oued Seguin, Mila, El Harrouch and Remier. The lifelines in the whole epicentral area were not affected.

The main shock was followed by a long sequence of aftershocks with one strong enough to add further damage, continuing until late December 1947. The succession of these shocks spread terror in Constantine and its vicinity where about 10000 people fled their homes to camp in the gardens or in the countryside. The earthquake was reported to the ISS by 50 seismological stations and was recorded up to Pasadena (U.S.A.) 93° away.

In the gorges of the Rhummel, the hot springs became suddenly reddish and muddy after the shaking while the flow of the springs and water temperature increased considerably. No other sign of ground features was reported.

2.13. 1949, February 17; Kherrata

$$M_S = 4.75 (\pm 0.07), I_0 = VII$$

Preceded by a series of foreshocks of with one strong enough to cause destruction of local dwellings, a damaging earthquake at night affected a relatively small area, Kherrata and its surrounding villages and douars. The main shock caused the loss of two lives, injured at least 16 and made around 350 homeless; it destroyed and/or badly damaged about 50 housing units and a few public buildings. The total cost of damage was estimated at 300 million French Francs. The shock was felt between Djidjelli and Bordj Menaiel (about 240 km) and Tixter and the coast (about 100 km). The earthquake caused significant to slight damage in Kherrata, Djermouna, Riff, Oued Marsa, Bougie, La Réunion, Ouled Embarek, Taskriout, Aidriss and

Beni Ismail. In Kherrata itself, where the earthquake caused general panic among the inhabitants, damage was slight and not significant, except at the gendarmerie buildings of which the partition walls were fissured and loosened. The church bell tower was seriously damaged. In contrast to European constructions, the local traditional gourbis in the surrounding isolated douars had their walls shattered and their roofs destroyed. The electric cables were cut in many places. At the douar Riff, where most damage was observed, the convent school sustained so much damage that it had to be evacuated. In the douar Dra El Caid, the Takléat part was badly damaged, 18 housing units being partly destroyed. Several gourbis collapsed in the douars of Djermouna and Ferhous. At Bradma, numerous gourbis were totally destroyed. Only the fall of chimneys and sections of walls was observed in Ouled Embarek. Also in Bougie, Darguinah, Ain Roua as in many other sites, houses were shaken enough to awake several sleeping people, although only minor damage was reported. The shaking was widely felt in Yakouren, Azzazga, Bordj Menaiel, Lafayette, Montaine as well as in other places, but no damage was observed.

The main shock was followed by many aftershocks, with one strong enough to add further damage, occurring at the frequency of two to three per day and continuing until end of May 1949. It was reported to the ISS by 42 seismological stations.

It is of interest to mention that besides the earthquake, the whole region experienced torrential rain and windstorm during that period.

The earthquake was associated with large fissures and important rockfalls and landslides in different sites. The most remarkable ground fissure, about 600 m long, was observed in Setif. Significant rockfalls, in the gorges of Chabet El Akhra, obstructed the national road 9 for several days and damaged the parapets in various places.

2.14. 1954, September 9; Orléansville
 $M_S = 6.70 (\pm 0.20)$, $I_0 = X$

A catastrophic earthquake in the early hours ruined the city of Orléansville and an important number of surrounding villages and douars. The main shock, which lasted 12 s, destroyed more than 33000 buildings, killing at least 1409 people (40 Europeans), injuring about 5000 and making 50000 homeless. The zone worst hit spreads from Orléansville to Ténès (about 40 km) and to Miliana in the east (80 km). The earthquake occurred without a foreshock but was followed by a series of aftershocks of which some were strong enough to add further damage. The shaking was widely felt in Algeria, as far south as Freneda, east as Tizi Ouzou, west as Oran and north as Granada, Alicante and the Balearic archipelago in Spain. The earthquake was recorded by all the seismological stations operating at that time, it was reported to the ISS by 211 stations. In Orléansville itself, it was hard to find a building unscathed, ninety percent of the houses were damaged seriously, about the third collapsed and of the remainder, fifty percent had to be condemned. 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, numerous apartment blocks and houses as well as public and hydraulic works. Only the Mosque survived the shaking. The railway lines between Alger and Oran were distorted and subsided in several places, particularly between Orléansville and Oued Fodda. Rupture of underground gas pipes and electricity cables were thrown up and set fires to furniture and buildings. Most of the telegraph lines were cut off. In the douars of Beni Rached, Beni Djerdine, 5 Palmiers, Flatters, Les Heumis and many others, most of the local traditional housing units were razed to the ground. Moderate damage was observed in douars such as Dupleix, Fromentin, Lamar-tine, Kherba, Malakoff and Francis Garnier. On the other hand, damage extended

outside the epicentral zone to Miliana where three douars (Tacheta, Chemla and Zougara) were totally destroyed and 118 inhabitants were killed. In the capital, Alger, the majority of the people were awakened and those in high rise buildings panicked, but no significant damage was reported. The shaking was strongly felt in the villages of Boufarik, Burdeau, Marengo, Medea, Moliere, Mostaganem, Relizane and Tiaret. No evidence was found concerning the earthquake effects in Bougie, Maillot, Sidi Bel Abbes and Tlemcen.

The earthquake was associated with spectacular ground deformations. In the epicentral zone, a major ground fracture of over 20 km long was produced and was surrounded by many bundles of small breaks that seriously slashed the soil. Some soil deformations have shown a vertical displacement over 2.50 m. Also the earthquake and its aftershocks triggered rockfalls and landslides, and produced crevasses in many places. Sand volcanoes, an indication of soil liquefaction, were found around the Marabout Sidi Djillali and the village of Beni Rached. Some springs in the region dried up, changed their flows and new ones emerged. The hot springs of Vauban vanished. The hydraulic works also suffered considerable damage; the Ponteba dam was tilted by 55 cm along the 80 m of its length and the pipe system experienced snapping, distortion and upheaval. Several submarine telegraph cables off the Algerian coast were broken.

2.15. 1955, May 8; Boucheral

$$M_S = 4.75 (\pm 0.20), I_0 = VII$$

Preceded by few slight shocks, a local damaging earthquake struck the Ténès-Francis Garnier coastal zone. The main shock destroyed several local traditional houses and farms, and damaged colonial constructions. The earthquake did not cause any loss of life, but a few were injured. Several aftershocks followed the main shock, lasting until early June 1955.

In Francis Garnier, Ténès and Boucheral, the shock provoked a general panic among the inhabitants, destroyed numerous gourbis and produced cracks in colonial structures. Farms in the vicinity, where few people were injured, sustained heavy damage. Livestock was buried under the rubble of the stables and animals killed. School was closed due to the extensive of damage. The electricity services were interrupted, but there was no damage to mains. In Duplex, Cavaignac and Mentenotte, damage was no more serious than cracks in walls and falls of plaster, but there was great alarm among the inhabitants. In Orléansville damage consisted of slight fissures in few walls. In Les Attafs, Charon, Rouina, Duperré and in other surrounding localities, the earthquake was widely felt, but no damage was reported. In the capital, Alger, 145 km distant, the shaking was seriously felt by the people living around the 14th floor in the high rise buildings of Champ de Manoeuvre. The earthquake was slightly felt in Fort de l'Eau, Medea, Lodi, Damiette, Letourneux, Molière and Inkermann.

The earthquake triggered many landslides and rockfalls in the cliff along the coast, particularly between Ténès and Francis Garnier.

2.16. 1955, June 5; Beni Rached

$$M_S = 5.10 (\pm 0.16), I_0 = VIII$$

A local destructive earthquake in the central Cheliff Valley, preceded by few slight foreshocks, destroyed a very small number of colonial and native Algerian constructions in Beni Rached and its immediate vicinity. The earthquake caused no casualties among the population. The main shock was followed by many aftershocks with one strong enough to be felt at Alger 170 km distant. The earthquake was recorded up to Pasadena (U.S.A.) 91° away and reported to the ISS by 98 seismological stations.

In Beni Rached, the earthquake totally ruined three colonial houses and five gour-

bis, and added further damage to structures already affected from previous shocks; it seriously frightened the inhabitants, who rushed outdoors. Much of the damage, which consisted of falling of walls, new cracks in structures and expansion of existing ones, was concentrated mainly in the localities of Kherba, Carnot, Orléansville, Oued Fodda, Les Attafs and Rouina. In Cherchell, Ténès, Inkermann, Littré as in other sites, the shaking was strong enough to cause considerable panic among the population, but no damage occurred. In Alger, many sleeping people were abruptly awakened by the shock and hanging objects were seen swaying for few seconds. The main shock was slightly felt in many settlements such as Fort de l'Eau, Letourneux, Tiaret, Mongolfier and Paul Robert. No evidence of any sign of ground deformations or liquefaction was reported.

2.17. 1959, November 7; Bou Medfaa
 $M_S = 4.90 (\pm 0.40)$, $I_0 = VIII$

In the early hours and preceded by two slight shocks, a destructive earthquake seriously affected about 80 percent of the houses, gourbis and public buildings in the area comprising Bou Medfaa, Hammam Righa, Ameer El Ain and their immediate surroundings. No one was killed and only two were injured but at least 500 people were rendered homeless as a result of the shock. A series of aftershocks followed the earthquake; they did not cause any further damage but seriously undermined the spirits of the inhabitants.

In Bou Medfaa, most damage consisted of the collapse of inner walls and ceilings, destruction of roofs, and cracking and uplift of floors. The health centre, a very recent construction, was severely damaged as were the gendarmerie buildings, the town hall, the «SAS» army barracks and the church. Farms around Bou Medfaa were totally destroyed, tombstones overturned and telephone lines were disrupted. No

damage was observed in the school or post office.

In Hammam Righa and Ameer El Ain, much of the damage consisted of the fall of chimneys and major fissures in walls.

In the epicentral area, there was a general panic and most of the people fled from their homes to the open. In Oued Djer, the deck of the bridge was cracked and uplifted. Also, cracks in walls and ceilings, fall of tiles, and breaking of glasses and dishes were observed in Oued Djer as well as in Affreville, El Affroun and Vessoul Benian. Damage was minor, consisting in fine cracks in walls and chimneys in localities such as N'Sour, Beni Mered, Affreville, Lavigerie, etc., where many people ran outdoors. Elsewhere in the epicentral zone, the shock was clearly felt, but caused no alarm. The earthquake produced a slight ground surface fissure in Bou Medfaa.

2.18. 1959, December 12; Oran
 $M_S = 4.55 (\pm 0.11)$, $I_0 = VII$

A moderate earthquake hit the coastal zone comprising Oran, Saint Cloud and Kristel, producing from significant to slight cracks in old buildings and causing considerable concern among the population within the plain of Sebkha. The shock occurred without a foreshock, but was followed by several aftershocks of less intensity, continuing until late January 1960. In Oran itself, the shock was strong enough to cause considerable panic among the inhabitants, particularly in the modern high rise buildings. Most damage in this city consisted of moderate fissures in walls and ceilings in old buildings in many districts. It was strongly felt at Saint Cloud and Kristel where it caused considerable alarm but only slight damage occurred such as cracks in walls and ceilings. In the surrounding villages and douars of Oran such as La Senia, Hassi Ameer, Mers El Kebir, Hassi Ben Okba... etc., the earthquake was seriously felt, causing some people to rush outdoors,

and provoked fine cracks in old walls. No damage was observed in localities such as Bou Sfer, Valmy, Sainte Barbe du Tlelat, Saint Leu... etc., although there was some concern but no serious alarm. Elsewhere in the epicentral zone, the shock was partly felt by the population, as far as east as Laspasset, south as Matemore and east as Tlemcen.

The earthquake produced a small ground surface fissure (35 cm wide and several metres long) and broke a water pipe within the city of Oran.

2.19. 1960, February 21; Melouza

$$M_S = 5.00 (\pm 0.27), I_0 = VIII$$

Without any premonitory sign, a destructive earthquake hit Melouza and its nearby villages and douars. The main shock, which caused the loss of 47 lives, injured 129 and made approximately 4900 homeless, destroyed about 600 local traditional dwellings. The earthquake was followed by a long sequence of aftershocks with some of them strong enough to add further heavy damage. Although damage and casualties were reported following the main shock, the possibility of cumulative damage remained from early aftershocks, heavy rain and a strong snowstorm which the region experienced in January 1960. The total cost of damage was estimated at 500 million French Francs.

In Melouza, 8 people were killed, 65 injured, 3600 rendered homeless and 70 percent of the houses were completely destroyed. In Beni Ilman, more than 50 percent of the local dwellings were devastated, killing 39 people, injuring 64 and rendering 1300 homeless. The newly built «SAS» army barracks were ruined. At the douars Mousquek and Makmen, some of the houses were totally destroyed while others suffered serious fissures, but no casualties were reported. In Sidi Aissa, Aumale and Ain El Hadjel, most of the damage consisted of cracks in walls and fall of ceilings. Strongly felt east of Melouza, at the junc-

tion of the Hodna and the Biban mountains, south of Portes-de-Fer, the shock was slightly felt as far as Alger.

The main shock and its aftershocks triggered many rockfalls and landslides in the epicentral area, particularly, north of Melouza where large fissures and landslides were observed. The earthquake was reported to the ISS by 131 seismological stations.

2.20. 1960, February 29; Agadir

$$M_S = 5.70 (\pm 0.23), I_0 = X$$

Late at night a catastrophic earthquake hit the southwest part of Morocco. The main concentration of damage was the city of Agadir and its nearby villages and douars, where 12000 people perished, at least 12000 were injured and thousands of survivors were trapped under the debris. A number of localities to the north and northeast of the city were devastated. The earthquake affected structures in the zone comprised between Ounarha, Es-Saouira, Imi N'Tanout, Taroudannt, Ait Baha and the coast. The shaking was clearly felt as far south as Ifni, east as Bou Azzer and north as Casablanca. There were two foreshocks of which the second one was strong enough to be felt by all the population of Agadir. A hundred shocks followed the earthquake with early ones of comparable size, which achieved the destruction of many buildings. The main shock was recorded by almost all the seismological stations in the world, up to Byrd 13700 km distant.

In Agadir, the earthquake completely destroyed the Moroccan constructions at the rate of 100 percent and the European structures at about 70 percent. Telephone lines, electricity and water services were interrupted. A great number of villages and douars around Agadir such as Tildi, Tagadir des Ait Lamines, Anou N'Feg, Taourirt, Iferkes, Immi Mikki and Aourir-Assersif, where about 600 people lost their lives, suffered heavy damage and destruction. Within 12 km radius, the local tradi-

tional dwellings were totally destroyed, but the intensity of damage decreased rapidly beyond this zone. On the periphery of Djebel Lgouz (Mesguina), the destruction became partial. In the plain of Souss, damage was very slight and limited to cracks in walls.

The earthquake produced only minor landslides and fissures. These cracks or fissures were mainly found in the streets of Agadir, which are built on filled ground. They were local and longitudinal and crossed the asphalt and filled ground alike. Transversal fissures were rare and not important. The longitudinal fissures were very significant because they were all aligned along a WSW-ENE direction which superposes the south Atlas tectonic accident. Some of these fissures presented on average a throw of 5 to 8 cm and in a few places up to 30 cm. In the harbour, major fissures caused significant damage to the port facilities. There were no significant tectonic features observed in the whole area. Landslides and rockfalls were reported wherever the roads crossed gorges of calcerous cliffs. Sand volcanoes were observed in the zone of the dune near the mouth of River Souss. Very near this liquified area, a ground surface fissure of several tens of metres long, about 30 cm wide and a throw of 20 cm was produced. As a hydrological effect, only the flow of the spring in the region of Tabadkoukt (northeast of Agadir) increased considerably. The shaking did not provoke any significant roughness in the ocean.

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

2.21. 1965, January 1; M'Sila

$$M_S = 5.45 (\pm 0.20), I_0 = VIII$$

Preceded by a local but damaging foreshock four hours earlier an earthquake at night struck a relatively small area in the Hodna plain of which M'Sila was the cen-

tre. The earthquake caused a loss of at least 5 lives, injuring 25 and destroying 3145 local traditional housing units; it rendered more than 25000 homeless in M'Sila and its surrounding douars. A long series of shocks followed the earthquake of which some were strong enough to add further damage, but no casualties were declared. The main shock was recorded in almost all seismological stations operating at that time, it was reported to the ISC by 162 stations.

It is noteworthy that the epicentral zone had experienced torrential rain, before and after the earthquake, which considerably aggravated the disaster.

In M'Sila, 1304 housing units were totally destroyed, 673 heavily damaged and threatening collapse, and 687 were seriously cracked. About 17815 homeless people were living in relief camps around M'Sila alone. There was a general panic among the inhabitants. At the oldest parts of M'Sila, in the douars of Kherbet Tellis and Kraghna, most of the houses were totally shattered. The mosque was also destroyed. The newly built town hall, just completed, was seriously cracked. The Oued Ksob Dam, the only masonry dam in the region, located at 15 km north of M'sila, did not suffer any damage. Stone constructions built downstream from the dam were fissured. 480 other housing units were totally destroyed in other localities of the region at Chellal, Pelaa, M'Cid, Misrir, Melouza, Ouled Mansour, Hammam Dhelma, Maadid, Ouled Deradj, Hammam Selai and Oukhnis, but no casualties among the population were declared. In Boghari, Boussaada and Bordj Bou Arreridj, the earthquake was strongly felt and caused only slight damage, there was more fear than harm. At Bouira, Maillot and Beni Mansour, the shaking was seriously felt, causing some concern among the inhabitants but no serious alarm or damage. The earthquake had caused great concern among the inhabitants in a high rise building of 15 storeys at the capital Alger. The shaking was slightly felt as far Alger in the

north, N'Gaous in the east, Trolard Taza in the west and Ben Srour in the south.

It is uncertain whether the small mass of fallen earth in the river bank and the cracks on the road were associated with the earthquake or with the heavy rain.

2.22. 1980, October 10; El-Asnam

$$M_S = 7.45 (\pm 0.33), I_0 = IX$$

At noon a violent earthquake struck the Central Cheliff Valley affecting a rather densely inhabited region. It occurred without a foreshock though other reported phenomena could have been premonitory. On the other hand, the main shock was followed by a long series of aftershocks, during several months, with some of them strong enough to add further damage and casualties among the population. The earthquake was reported to the ISC by 514 seismological stations. The main shock and its largest aftershock caused the loss of 3000 lives, injured at least 8500 and made 400000 homeless; together they completely destroyed 25000 housing units, damaged around 40000 beyond repair and inflicted serious to slight damage to 15000 others in addition to the destruction of numerous public buildings, major stores, industrial installations, lifeline systems, transport and commercial facilities, and public and hydraulic works in the whole affected zone. The earthquake affected all levels of economic development. The total cost of damage was estimated at U.S. \$ 5 billions. The zone of greatest structural damage, loss of life and ground deformations was confined within the narrow area including El-Asnam, Sendjas, Zeboudja, El-Abadia, Oued Fodda, Beni Rached, El-Attaf and Oum Drou.

In El-Asnam itself, as much as 1500 people perished, 4000 were injured and about 88000 rendered homeless; as much as 20 percent of the building stock was completely destroyed, 60 percent severely damaged and the remainder were either slightly affected or survived without any damage.

Several modern structures suffered pancake collapse in which several hundred people were killed under their debris. In a radius of about 40 km around El-Asnam, most damage consisted of the collapse of various structures, loss of life and ground deformations. Khemis Miliana 60 km away was the last town where damage could be clearly seen. In the capital Alger 170 km distant, the shock was strong enough to make people panic and flee from their homes to the streets; 16 buildings in the Alger-Casbah, seriously cracked and threatening of collapse, were evacuated. Also in Blida, Tiaret, Frenda and Mostaganem, the shaking caused considerable panic among the inhabitants, but no damage was reported. In Spain, at Murcia, Gandia, Alcira, Valencia and Ibiza Island, the earthquake caused panic movements of the population and slight damage to buildings. The radius of perceptibility was fairly large and the shaking was felt as far east as Bejaia, south as Laghouat, west as Tlemcen and north as Cordoba and Barcelona in Spain. There is no evidence that the shock was felt in Morocco.

The earthquake was associated with an extensive ground deformations; it is the first known event to produce large surface rupture in the western Mediterranean area. Details of observed ground features and their association with the tectonic environment of the region are given by Ambraseys (1981a,b). One of the remarkable effects of this earthquake is that an equivalent amount of both extensional and compressional deformations was observed which implies a rather complex deformation mechanism. Damage to the surface as a result of the shaking was extensive, disastrous and varied. Much land was sunk and some was uplifted; a lake was formed, the flow of springs was altered, water levels in wells were modified and the courses of Oued Cheliff and Oued Fodda were changed. Fissures, large cracks, landslides, sand blows and extrusions of various kinds were common. The manifestation of the earthquake itself was a visible surface fault passing very

close to Oued Fodda. It was about three kilometres west of Oued Fodda, where the fault cut the Alger-El-Asnam railway line and the Oued Cheliff bed. Among the most impressive sights left behind by the earthquake were the bending of the railway lines and the uplifting and overturning of the freight train that was crossing the fault at the moment the shaking occurred.

2.23. 1985, October 27; Constantine

$$M_S = 5.70 (\pm 0.27), I_0 = VIII$$

Two slight shocks preceded a damaging earthquake which hit early at night in the relatively densely populated region of Constantine. The earthquake completely destroyed old dwellings and farms, and slightly damaged modern buildings in the affected zone; it caused the loss of 5 lives and injured over 300. The main shock was followed by several aftershocks of less intensity which seriously undermined the spirits of the inhabitants, and continued until late November. The shock was reported to the ISC by 474 seismological stations and was recorded up to Taravao (Tahiti) 152° distant. Most damage was observed in the zone included between Constantine, El-Khroub and Ben-Yakoub, where the village of El-Aria was the centre. In El-Aria, numerous houses and farms were totally destroyed, five people perished and several others were injured when fleeing their collapsing homes. The shock caused a general panic among the inhabitants. At Ben-Yakoub, damage was extensive as many adobe and stone dwellings collapsed. In Constantine itself, the shaking was strong enough to make people panic and rush outdoors. Only slight damage was observed in modern buildings whereas in the old part of the city most constructions sustained severe cracks. At El-Meridj and El-Khroub, old houses were completely destroyed while the new buildings suffered only slight damage which consisted mainly of horizontal fissures in masonry infill and shear walls. Elsewhere in the epicentral region, the

earthquake did cause no damage but was widely felt as far east as El-Kala and Souk-Ahras, west as Setif and Jijel, south as Batna and north as the coast. The earthquake produced significant ground surface ruptures in the epicentral zone. A 3.8 km ground surface fissure appeared in small segments between Kef Tassenga and Koudiat Ben Ghorara, another 700 m long one in Ben-Yakoub and in Aioun Dardar, the earthquake provoked graben-like subsidences and landslides. There was no sign of soil liquefaction.

2.24. 1989, October 29; Chenoua-Tipaza

$$M_S = 5.70 (\pm 0.29), I_0 = VIII$$

A destructive earthquake and a damaging aftershock in the Chenoua-Tipaza region completely destroyed and/or seriously damaged 7500 housing units and 500 other different constructions as official buildings, schools, hospitals, cultural and sport centres, museums, shops, industrial plants, and bridges. There was no information about any premonitory sign of any kind preceding the main shock. Numerous aftershocks, continuing until late December 1989, were recorded of which some were strong enough to add further damage in the epicentral zone. The main shock and its largest aftershock killed at least 35 people, injured about 700 and rendered approximately 50000 homeless. They were respectively reported by 517 and 415 seismological stations to the ISC. Worst damage, which consisted of collapse of old structures and few new buildings and significant cracks and fissures on walls and roofs of some relatively better built constructions, was concentrated at the sites of Nador, Sidi Moussa, Sidi M'Hamed, Chenoua Mount, Menaceur, Bakoura, Sidi Amar, Tipaza, Cherchell and their close surroundings. In the village of Nador and its dependent douars, 680 housing units were shattered to the ground and around 1000 seriously damaged, where 22 people perished and 300 were injured. In scores of douars as in

Hamelet Nora Lamouren where the destruction of gourbis reached 100 percent and five children, trapped under the rubble, were killed. Numerous of these douars are sparsely distributed on and around the Chenoua Mount sustained extensive damage but were not mentioned in the press. In Tipaza, the shocks severely damaged about 700 houses and public buildings rendering about 5000 people homeless. In Cherchell, forty percent of the housing building stock, as well as various public buildings, were destroyed or heavily damaged, making about 21000 homeless. Electricity services were interrupted for all night which made the relief difficult. At Bakoura (city of Cherchell), occurred one of the few cases where an engineered modern reinforced concrete school structure, built in 1982, sustained damage beyond repair and had to be demolished. The bridge on Oued Hachem, of which the deck was displaced, suffered damage such as cracks in its masonry abutments, and that of Sidi Ben Youcef was so seriously fissured that it had to be strengthened. In Tissemsilt 125 km away, Tizi Ouzou 145 km distant and Ain El Hadjar (Saida) 285 km from Tipaza, the earthquake caused considerable alarm among the population who fled their homes, but no damage was reported. In the capital Alger 60 km away, the earthquake heavily damaged six houses in the Casbah and accentuated existing cracks and fissures in the old quarters as the Haute and Basse Casbah, Bab El Oued, Belcourt, Kouba, Badjarah, El Hamma and El Harrach and caused a general panic among the population who rushed outdoors. The shaking was slightly felt as far east as Azefoun, south as Ain Oussera and Tiaret, west as Ammi Moussa and north as the Baleric Isles 360 km distant. It is noteworthy that other engineered structures and presumably better built constructions in the epicentral zone remained unscathed.

The main shock triggered strong-motion instruments which indicate a peak ground horizontal acceleration at 0.28 g with a ver-

tical component of 0.14 g at Cherchell 12 km distant.

The earthquake was associated with significant ground surface fissures, rockfalls and landslides. At the southern flank of Chenoua Mount, ground surface cracks expanded along a distance of four kilometres with an east-west overall trend. The longest surface rupture, which consisted of two unbroken segments each of 150 m long, was observed at Sidi M'Hamed. Rockfalls, from Chenoua Mount, blocked the coastal road between Tipaza and Cherchell. Landslides were also reported on and around Chenoua Mount. No evidence of any sign of soil liquefaction was found.

3. Information on individual subjects

Some particular earthquake effects or associated phenomena of interest retrieved from the same macroseismic source documentary materials are summarized in this section.

3.1. Faulting

Faulting in the Maghreb region has been clearly reported in four cases during this century; Orléansville 1954, El Asnam 1980, Constantine 1985 and Chenoua-Tipaza 1989 earthquakes. Extensive ground deformations were produced by the 1954 earthquake, but the location and the actual movement of the fault-break remain questionable (Capot-Rey, 1954; Dalloni, 1955; Rothé, 1955; Thevenin, 1955). The 1980 earthquake was also associated with a broad faulting which was mapped immediately after the event by Ambraseys (1981a,b). Significant ground surface breaks, which may correspond to the north-eastern continuation on the Ain Smara Fault, were produced by the 1985 earthquake and analyzed and mapped by Bounif *et al.* (1987). Extensive ground surface breaks with 4 km of fault length and 7 cm of vertical displacement appeared in the

epicentral zone after the 1989 Chenoua-Tipaza earthquake, they were studied shortly after the event by Meghraoui (1991).

Other ground surface ruptures of less importance were reported in Constantine 1908, Ben Chabane 1924, Kherrata 1949, Bou Medfaa 1955, Oran 1959, Melouza 1960 and Agadir 1960.

3.2. Landslides

Cases of landslides are far more numerous during earthquakes in the Maghreb region. Some of the most significant are those that occurred during the Carnot 1934, Guelma 1937, Berhoum 1946, Kherrata 1949, Orléansville 1954, Boucheral 1955, Melouza 1960, Agadir 1960, El-Asnam 1980, Constantine 1985 and Chenoua-Tipaza 1989 earthquakes. Often these landslides accentuated the damage to the douars perched on steep slopes on the flanks of different mountains. Graben-like subsidences were also produced during the 1954 and 1985 earthquakes.

3.3. Rockfalls

Many of the earthquakes in the Maghreb region are associated with rockfalls which, in some cases, had added further damage. Earthquakes that provoked significant rockfalls are Aumale 1910, Cavaignac 1922, Carnot 1934, Guelma 1937, Mansoura 1943, Berhoum 1946, Kherrata 1949, Orléansville 1954, Boucheral 1955, Melouza 1960, El Asnam 1980 and Chenoua-Tipaza 1989.

3.4. Hydrological effects

Modifications in flows of springs, water table level and rise of water temperature often appeared after the earthquakes. Some of these features, which sometimes were beneficial to the community, occurred

in Boghari 1903, Cavaignac 1922, Ben Chabane 1924, Inkermann 1928, Carnot 1934, Guelma 1937, Mansoura 1943, Constantine 1947, Orléansville 1954, Agadir 1960 and El Asnam 1980 earthquakes.

Water was flowing in ravines which were dry and water level in wells and oueds rose up to 30 cm (Cavaignac 1922 earthquake). A lake of about 2.5 square kilometres in area was formed, the flow of springs was altered, water levels in wells were modified and the courses of Oued Cheliff and Oued Fodda were changed (El-Asnam 1980 earthquake).

3.5. Soil liquefaction

Soil liquefaction is likely to occur when a loose sand is in saturated conditions and shaken by a strong earthquake which results in a build up of hydrostatic pore pressure and decrease of the effective stress.

Sand blows, indication of soil liquefaction, have been observed in only three cases, but did not cause any damage which may be related directly to this phenomenon. Soil liquefaction was reported in Orléansville 1954, Agadir 1960 and El-Asnam 1980 earthquakes. No evidence has been found of any detailed study having been made of the soil liquefaction during these earthquakes.

3.6. Tsunamis

Tsunamis are the water waves produced impulsively by earthquakes through tectonic displacement, submarine slides or landslides and rockfalls into deep water. Tsunamis merit great attention because of the loss of life, damage to the man-made structures and the alteration of the landscape that they may cause (Wiegel, 1970; Ambraseys and Melville, 1982).

Many earthquakes had their epicentres offshore in the Mediterranean sea or the ocean, but because of their small magnitudes they do not produce any noticeable

water waves. No evidence was found of tsunamis causing any concern in the Maghreb region during this century. However, several sailors described a sea wave during the main shock of Chenoua-Tipaza 1989 earthquake and in the port of Tipaza, the sea was reported to have retreated by more than one metre, but no permanent changes in sea level were reported along the coast of the affected zone (Meghraoui, 1991).

3.7. *Socio-economic implications*

In the wake of destructive earthquakes in the Maghreb region, as elsewhere, governments show a great concern and devotion for impressive reconstruction and rehabilitation plans. In the heat of the disaster, calls from the authorities are quickly answered by national companies and organizations as well as international bodies whose help, unfortunately, does not last more than few weeks after the interest of the government decreases or the problems of reconstruction become more involved and less interesting. Generally, after an earthquake, an interministerial commission is formed in order to apply the decisions of the government in the field, but as the available funds and means are found to be insufficient to carry out the ambitious or political reconstruction plans, the national interest in the affected region dies out and the victims are left to fend for themselves.

During the last ninety years, as in other parts of the world, the human and political aspects of an earthquake disaster were rarely made known to the public. In some cases, earthquakes not only destroy the buildings, but also devastate the whole social structure as well as the socio-administrative organization of the region. In few seconds, thousands of families were cruelly separated, many children became orphans and many fathers and mothers found themselves without families (Orléansville 1954, Agadir 1960, El-Asnam 1980). The sudden

disruption of the local economy, together with the everyday socio-economic conditions, after the hope of reconstruction fades, very often cause the inhabitants to emigrate to other regions of the country, leaving the old people, women and children behind.

Often the political authorities use the allocated funds to reconstruct a certain town or village which has greater political influence or prestige and neglect much more severely damaged small villages and douars, which leads in some cases to local unrest. For instance, after the Chenoua-Tipaza earthquake, most of the relief and national attention was concentrated towards Tipaza where the son in law of the President was the Governor (Wali of Tipaza). Naturally, this contributed to anti-government demonstrations against the discrimination between the people in towns and those in villages and douars. The affected people in many places obstructed national roads for a few days in order to obtain the relief; the gendarmerie had to intervene using teargas bombs to break up the crowd.

Sometimes, a destructive earthquake may have beneficial side effects, such as the accommodation of people in new state apartments or helping them to rebuild their houses. After the Chenoua-Tipaza earthquake, several families took the opportunity to solve their crucial housing problem. In fact, everybody who was unhappy with his house (old, isolated, damaged, crowded, etc.) was asking for a relief tent because, as reported in the press (1989): «... having a tent after the earthquake means you were made homeless and you qualify for relief or may be accommodated in a new state apartment».

For agricultural regions, the earthquake may have positive or catastrophic side effects on the whole zone. For instance, in the Orléansville 1954 earthquake, the destruction of the irrigation system in the plain of the Cheliff caused tremendous losses to the French settlers. In some cases, it brings new hopes for the region repre-

sented by the rise in levels of wells and water table, and the appearance of new springs or lakes, as in the El-Asnam 1980 earthquake.

Also many other problems such as looting, robbery, corruption and misuse of funds, not limited to the Maghreb countries, were observed during the past destructive earthquakes.

4. Conclusions

This chapter deals with the felt effects of the largest and most informative earth-

quakes to have occurred in the Maghreb region during the twentieth century and which are important for engineers, earth scientists and for planners. For each event, a brief description summarizing the original information is given so that the reader does not have to go to the original sources of these events. One conclusion that may be drawn from this sample of earthquakes is that damage, when evaluated uniformly at a large enough number of sites, like other semi-empirical measures of physical phenomena, may reveal regular damage patterns which can be taken as a simple damage model for the region under survey.