Strong Algerian Earthquake Strikes Near Capital City

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On 21 May 2003, a damaging earthquake of Mw 6.8 struck the region of Boumerdes 40 km east of Algiers in northern Algeria (Figure 1). The main shock, which lasted ~36-40 s, had devastating effects and claimed about 2300 victims, caused more than 11,450 injuries, and left about 200,000 people homeless. It destroyed and seriously damaged around 180,000 housing units and 6000 public buildings with losses estimated at $5 billion. The main shock was widely felt within a radius of ~400 km in Algeria. To the north, the earthquake was felt in southeastern Spain, including the Balearic Islands, and also in Sardinia and in southern France.

The main shock location, which was calculated at 36.91°N, 6.53°E (15 km offshore of Zemmouri; Figure 1), and the local magnitude (M, 6.4) are from seismic records of local stations. International seismological centers obtained M, 6.8 (NEIC) with a thrust focal mechanism solution and 1.83 x 1026 dyne.cm for the seismic moment. A sequence of aftershocks affected the epicentral area with two strong shocks reaching Mw 5.8 on 27 and 29 May 2003. Field investigations allowed us to assign a maximum intensity X (European Macroseismic Scale 98) and to report rockfalls, minor surface cracks, and liquefaction phenomena. The main shock was not associated with inland surface faulting, but one of the most striking coseismic effects is the coastal uplift and the backwash along the littoral of the Mitidja basin.

The Zemmouri earthquake is among the largest recorded events in North Africa. The heavy damage and death toll can be explained by the large magnitude, the poor quality of the constructions, and site amplification effects.

Seismicity and Neotectonic Setting

Northern Algeria experienced several disastrous earthquakes in the past: in Algiers on 2 January 1935 and 2 February 1716, with peak Modified Mercalli Intensity IX; in Oran on 9 October 1790 IX; in Blida on 2 March 1825 IX; in Mouzaia on 2 January 1867 IX; in El Asnam on 10 October 1980 M, 7.3; in Oued Djer on 31 October 1988 M, 5.6; in Mont Chenoua on 29 October 1989 M, 6.0; and in Ain Benian on 4 September 1996 M, 5.3 [Rothe, 1990; Ambrosetti and Vogt, 1988; Meghraoui, 1991; Benouar, 1994; Mokrane et al., 1994; Maucoche et al., 1998; and Harbi et al., 2003]. The active faulting and occurrence of past earthquakes indicate that the Algerian region is an active zone with significant seismic potential (Figure 1).

The Mitidja basin is part of the Tell Atlas, an east-northeast-trending, fold-and-thrust belt along the plate boundary in North Africa. The Quaternary tectonics, reverse faulting, and normal north-west-south-southeast compression movements are consistent with thrust focal mechanisms of recent earthquakes that result from the 5-6 mm/yr of convergence of Africa toward Eurasia [Argus et al., 1989]. The Tell Atlas may accommodate 2-3 mm/yr of shortening along the main thrust system of the plate boundary zone [Meghraoui and Douriez, 1996]. The Mitidja basin is bounded to the south by the Blida fold-and-thrust system, which corresponds to imbricated southeast-dipping thrust sheets. The northern side of the flat basin is limited by the Sahel active fold parallel to the coast. The fold scarp is probably related to a hidden reverse fault where the westemmost section produced the Mont Chenoua earthquake in 1989 [Meghraoui, 1991] (Figure 1).

Surface and Macroseismic Effects

Ground deformations with rock falls, landslides, and liquefaction were observed between Bordj El Bahri and Delliys and mapped soon after the mainshock, the zone of maximum damage. Minor cracks, fissures, and small landslides are distributed parallel to the coastal cliff along a 10 km distance. Various geological and hydrological effects were also observed: altered flow of springs, modified water level in wells, liquefaction, and extrusion of sand and sliding of river banks between Algiers and Delliys (see Figure 2). The uplift of individual rocks in the sea and emergence of algae level measured in different places along the coast, with a maximum of 0.80 m between Boumerdes and Zemmouri El Bahri, suggest a vertical deformation with possible fault emergence a few kilometers offshore.

Macroseismic effects: The earthquake of 21 May generated severe damage in areas and cities and villages located along the coast between Algiers and Tizirat, and further south to Bordj Menaiel (Figure 1). Many modern structures suffered “pancake” collapse in which hundreds of people perished. The Zemmouri village was almost completely razed, while other, nearby localities were severely damaged. We attributed an intensity X (European Macroseismic Scale 98) to the area between Delliys and Bordj El Bahri. Isoseimals of intensity X are localized (see Figure 1) and can be interpreted as probably due to the nature of the seismic source, wave path, and shallow depth, and the characteristics of the subsoil—which is generally clay and alluvial deposits—and to the poorly engineered recent building stock.

The main shock of 21 May triggered a tsunami with damaging waves of 1-3 m amplitude along the southern coasts of the Balearic Islands. Press reports described several hundred damaged vessels in harbors. In the epicentral area, several witnesses observed that, “the sea retired along the coast for about 200 m during...
Fig. 1. Isoseismals of the Zemmouri earthquake (red dashed lines) and the geological and tectonic background of the epicentral area [Meghraoui, 1991]. The Mitidja basin is bounded by thrust fault systems consistent with the focal mechanism solution of the mainshock (ETH Zürich). Original color image appears at back of volume.

Seismotectonics and Seismic Hazard Implications

The earthquake that struck the Zemmouri-Boumerdes region is among the largest seismic events recorded in northern Algeria. The seismic parameters and inferred surface rupture can be compared with the El Asnam earthquake [King and Vita-Finzi, 1981; Ouyed et al., 1981]; they suggest a thrust fault that is probably located a few kilometers offshore. Several important observations were made. Except for ground features such as hydrological effects, liquefaction phenomena, landslides, and rock falls, no significant surface ruptures were observed inland. Aftershocks are elongated in a northeast-southwest direction oblique to the coastline, and a coastal uplift was observed with an average 0.5 m of vertical movement between Boumerdes and Zemmouri El Bahri. The offshore continuation of the Bida reverse fault system may likely be at the origin of the 21 May earthquake.

The Zemmouri earthquake generated 0.58 g and 0.34 g of maximum acceleration recorded at 20 and 60 km from the epicenter, respectively. The observed maximum acceleration was fairly well predicted by the seismic hazard evaluation in the Algiers region by Aoudia et al. [2000]. For structures with a 0.25 s (4 Hz) period of vibration in the epicentral area, constructions should have been designed for an acceleration of 0.6 g [Naili and Benouar, 2000]. Unfortunately, the Zemmouri earthquake had an average frequency of 4 Hz and caused the phenomena of resonance for all of the structures in the range of 2-4 stories.

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Fig. 2. Surface effects and damage in the epicentral area are shown. No surface faulting was visible inland. Photos: Upper left, coastal uplift (average 0.5 m) marked by the intertidal zone (white band); upper right, liquefaction features (sand blows); lower left, "pancake" building collapse; lower right, secondary surface cracks. Original color image appears at back of volume.

Fig. 3. Aftershock distribution (gray circles, M>2) from 21 May to 10 June 2003. Open squares show historical seismicity since 1365; open circles show instrumental seismicity since 1900. Stars are mainshock locations of the 21 May 2003 seismic event (Mw 6.8) based on information from seismological centers. Focal mechanism solutions are CMT (Harvard) showing thrust faulting consistent with field observations and uplifted coastline.

References


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