

The Laalam (Algeria) damaging landslide triggered by a moderate earthquake ($M_w = 5.2$)

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Abstract On March 20th, 2006, a moderate earthquake ($M_w = 5.2$) struck the Laalam (NE-Algeria). The damage was centred in the Laalam village where four deaths, 68 injured and more than 40 housing units destroyed making dozens of peoples homeless. Damage and casualties are directly related to an earthquake-induced landslide occurred at 10 km far from the epicenter (ISC relocation). The landslide rupture, mapped by using a ground based survey, is striking NE-SW along a 1-km length rupture with a 45 cm of lateral displacement. The rupture plan is dipping 40° at the surface and showing horizontal striations. A 75 cm of pre-2006 lateral displacement is also observed indicating a repetitive behaviour of the landslide. The last time where the landslide was activated extends back to 1974 following another moderate earthquake. This landslide reminds us the high level hazard of induced ground failures due slope instabilities in mountainous zones of seismically active areas.

Keywords Algeria · Earthquake · Landslide · Damaging · Induced hazards

1 Introduction

Damage and casualties during moderate-sized to strong earthquakes are due either to strong shaking and/or to ground failure hazards such as surface faulting, landslides, liquefaction and rock falls (Bird and Bommer 2004). Many disastrous landslides triggered by seismic shaking has been studied throughout the world (Keefer 1984; Sassa et al. 2005; Rodriguez et al. 1999; Bommer and Rodriguez 2002; Hevenith et al. 2003; Keefer et al. 2006; Wang et al. 2007; Owen et al. 2008). Such landslides may cause huge economic losses by destroying infrastructures and constructions and may be the

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direct cause of losses of human lives. Therefore, it is important to consider these phenomena in any strategy of development and land planning in mountainous areas of seismically active regions. In Algeria, moderate to strong earthquakes are often associated with secondary hazards, particularly landslides (Gabert 1984; Benouar 1994; Bouhadad et al. 2003, 2004; Machane et al. 2008). During the Chenoua earthquake of October 1989 ($M_s = 5.7$), rock falls obtruded roads and, hence, delaying the rescue operations. During the May 21, 2003, earthquake ($M_w = 6.8$), many landslides were observed and mapped in the epicentral area (Bouhadad et al. 2004) causing damage mainly to roads. Furthermore, submarine landslides has been described following strong earthquakes of El-Asnam 1954 ($M_s = 6.5$), El Asnam 1980 ($M_s = 7.3$) (Vogt 1984) and Zemmouri 2003 ($M_w = 6.9$); These landslides disturbed telephone links between Europe and Algeria by cutting many submarine cables (Benouar 1994; El Robrini 1986). In this paper, we aim to present an example of damaging earthquake-induced landslide and discuss the implication for induced hazards in active zones, particularly in mountainous areas.

2 The earthquake and seismotectonic setting

On Monday March 20, 2006, at 20 h 44 mn (GMT+1) a moderate earthquake struck northeastern part of Algeria. The epicentral area is centered in Laalam mountainous

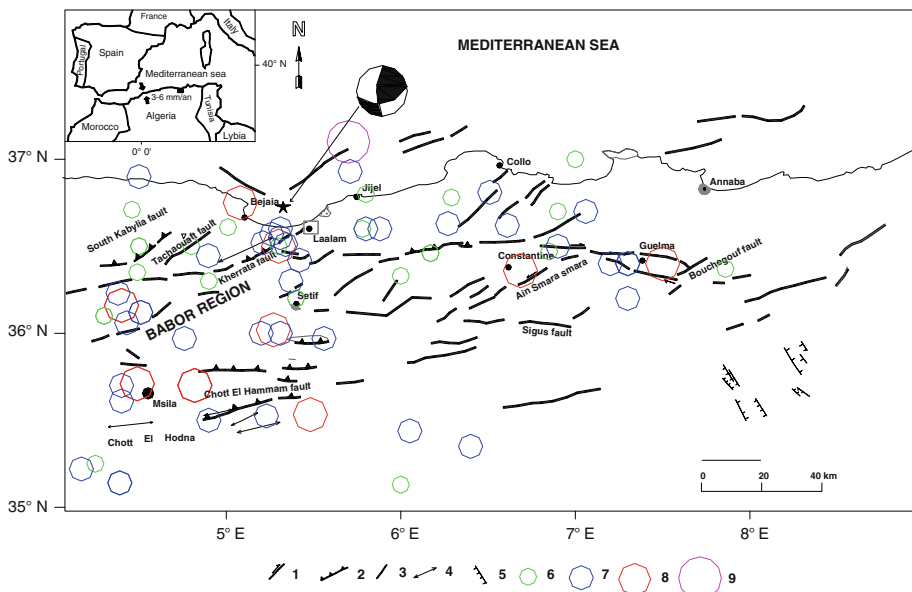


Fig. 1 Seismotectonic map of the Babor region showing the main geological units and active faults (Rothe 1950; Meghraoui 1988; Meghraoui et al. 1996; Harbi et al. 1999; Bouhadad et al. 2003). Epicenters are from Mokrane et al. (1994) and Benouar (1994). Focal mechanisms of the Laalam March 20th, 2006, earthquake (INGV). 1 = strike slip, 2 = reverse fault, 3 = neotectonic fault, 4 = anticline axis, 5 = normal fault, 6 = $[4.0 > M_s \geq 3.0]$, 7 = $[5.0 > M_s \geq 4.0]$, 8 = $[6.0 > M_s \geq 5.0]$, 9 = $[M_s > 6.0]$. The star indicates the Laalam earthquake epicenter (ISC)

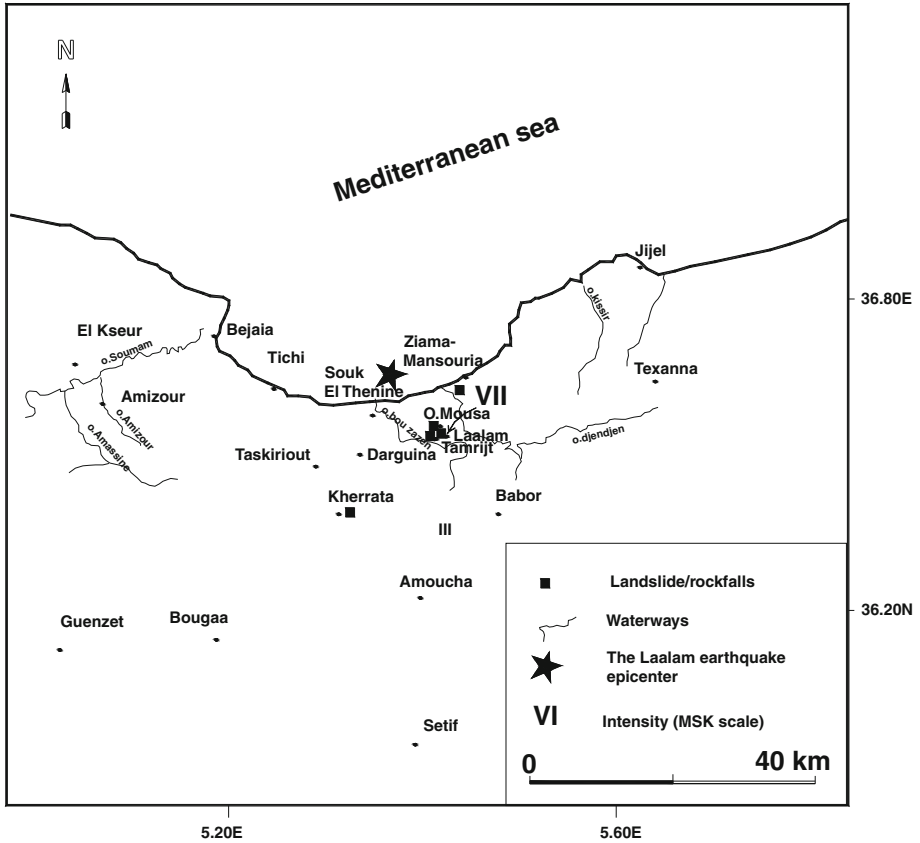


Fig. 2 Geographical setting of the area affected by the Laalam March 20, 2006, earthquake and the induced landslides

region (Fig. 1). This shallow earthquake was felt about 80 km around the epicenter as far as Akbou to the west and Djemila (Setif) to the east (Fig. 2). However, the damage is much localized in the village-dweller of Laalam where 4 peoples were died, 68 injured and more than 40 housing units destroyed making dozens of peoples homeless. The main shock epicenter was located at latitude of 36.68N and longitude of 5.33E (USGS), very close to the ISC epicenter (36.70N and 5.32E). The magnitude of the main shock was calculated by different specialized organisms is: $M_w = 5.2$ (INGV), $M_w = 5.1$ (IGN), $M_w = 5.3$ (ETHZ), $M = 5.8$ (CRAAG, Algerian center). Focal mechanism yield an almost reverse faulting with a strike component (INGV). The affected area belongs to the Tellian Atlas chain of Algeria which consists of the peri-Mediterranean plate boundary belt where the African and the Eurasian tectonic plates are converging in the NW–SE direction (Argus et al. 1989; Nocquet and Calais 2004). The amount of shortening ranges from 3 to 6 mm/year (De Mets et al. 1990). As a

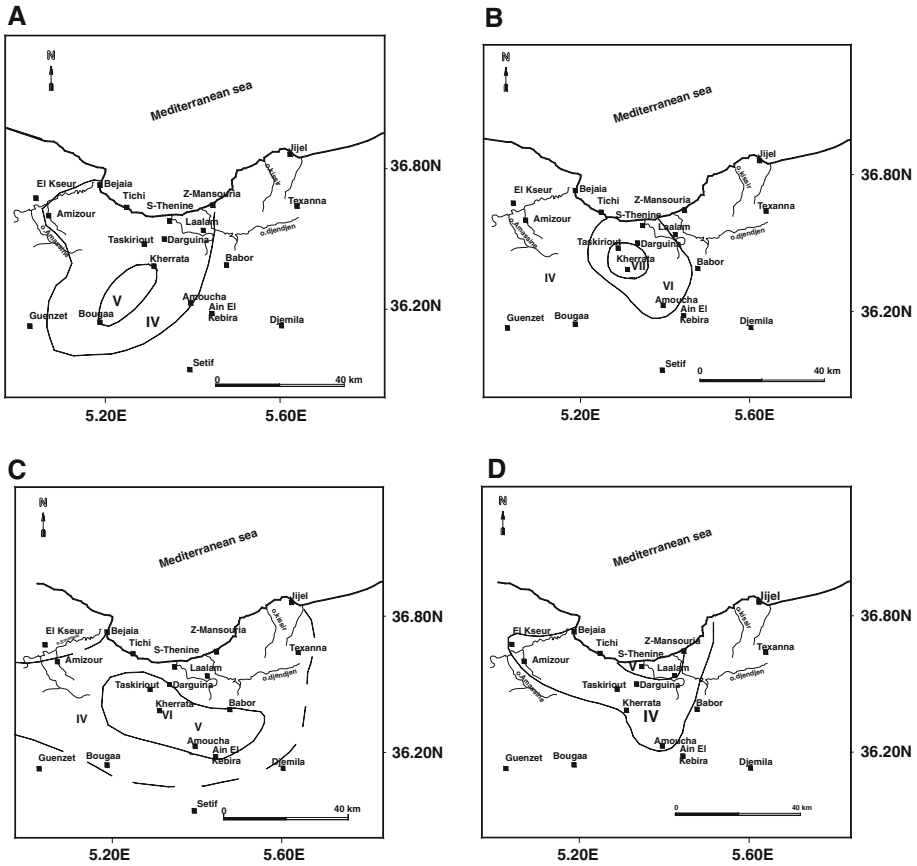


Fig. 3 Main historical seismic events occurred during this century in the studied region. **a** The October 21, 1985, earthquake ($I_0 = V$), **b** the February 17, 1949 ($M_s = 4.7$, $I_0 = VII$) earthquake, **c** the June 28th 1974 ($M_s = M_s = 5.0$, $I_0 = VI$) earthquake and **d** the April 6, 1972 ($I_0 = V$) earthquake (Mokrane et al. 1994)

result of this seismotectonic setting, several active faults, mainly reverse faults, which may be blind or not are described offshore and inland (Meghraoui 1988, 1991; Bouhadad 2001; Meghraoui et al. 2004; Deverchère et al. 2005). These faults produced during the last centuries many moderate to strong- sized earthquakes (Mokrane et al. 1994; Ambraseys and Vogt 1988; Benouar 1994). Geologically, the studied region belongs to the Babor thrust sheet area formed by Jurassic-Cretaceous calcareous and marl. The previously identified active faults in region are (Fig. 1): (1) the Kherrata fault which produced the February, 17, 1949 ($I_0 = VII$, MSK scale) earthquake (Rothe 1950; Meghraoui 1988), likely the Laalam 2006 earthquake, and other moderate earthquakes occurred in the region (Fig. 3), (2) The Tachaoaft fault which produced the November 10, 2000, earthquake ($I_0 = VII$, MSK scale) (Bouhadad et al. 2003).

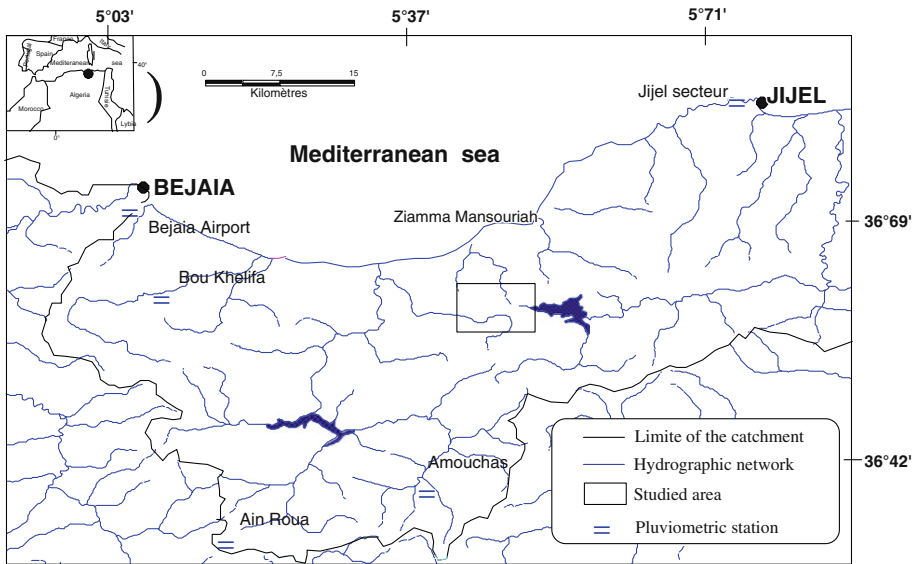


Fig. 4 Hydrographical network of the studied area and the localisation of the used hydro-climatic stations (Source, ANRH)

3 The landslide

3.1 Climate, topography and hydrogeology of the site

The studied area is characterized by a Mediterranean climate with dry seasons (June–September) and rainy, sometimes snowy, winters (October–April). Based on analysis of data from 05 hydro-climatic stations, for the period of 1974–2006, it appears that the annual average precipitations range between 600 and 900 mm (Figs. 4, 5); Eighty percent (80%) of these precipitations fall between December and February as flash flood. From geomorphological point of view, the earthquake occurred in area which consists of elevated crests exceeding 1,000 m in altitude and steep sides (about 70°) as well as deep waterways alimented by several spring flowing through rock fractures. The drainage is characterized by a densely constituted network of waterways flowing mainly from the SE to NW (Fig. 6). The Laalam village is built on relatively steep slope at a mean altitude of 400 m (Fig. 5a).

3.2 Geology of the site

In term of local geology, the site belongs to the external domain of the Tellian Atlas chain which consists of sheets and thrusting deformation. Lithologically, Jurassic limestone and Cretaceous marls are well developed while Neogene and Quaternary deposits are very sparse. Quaternary deposits correspond to down slope accumulated colluviums on which the Laalam village was settled (Fig. 5). The materials involved in the slide mass are constituted by colluviums with cretaceous marls at the bottom of the slide (Fig. 7).

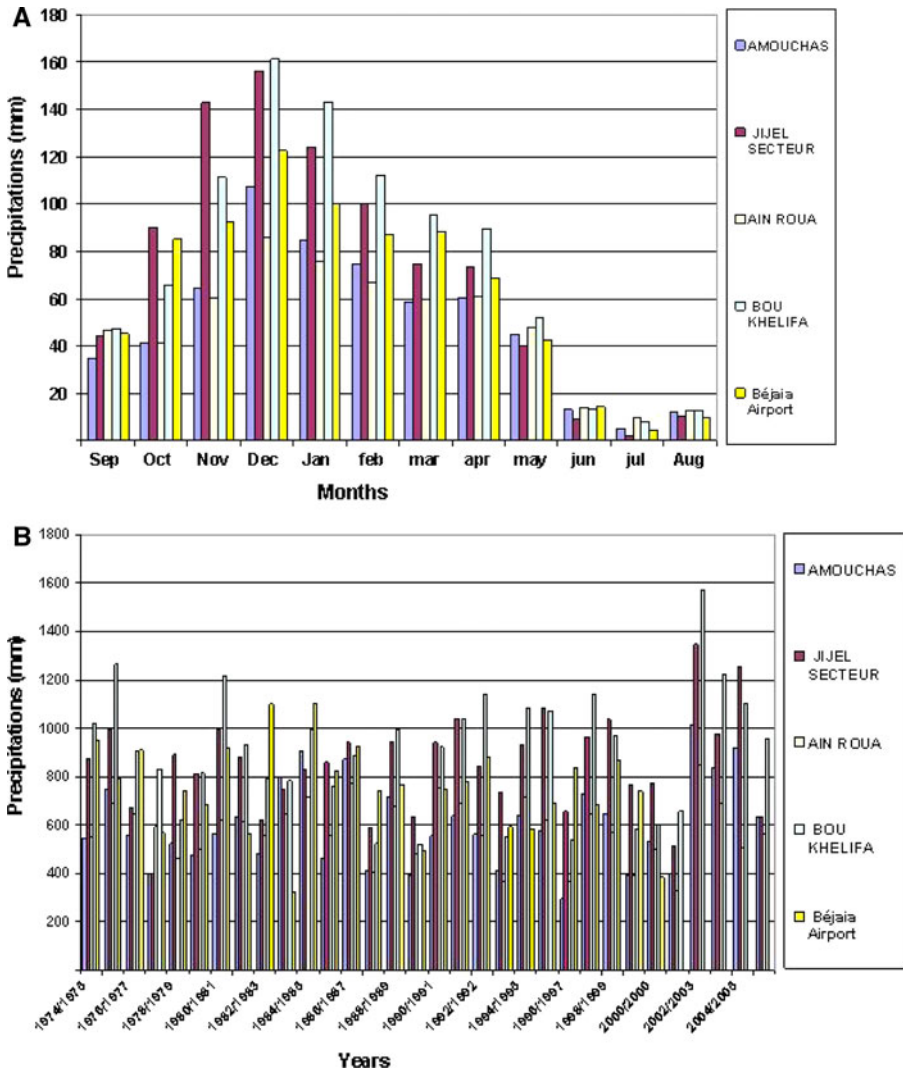


Fig. 5 a Monthly means of precipitation for the period of 1974–2006 in the studied region. b Annual distribution of precipitation during the period 1995–2005 (data are from ANRH And ONM of Algiers)

3.3 The 2006 reactivation of the landslide

The Laalam earthquake triggered several landslides despite its small size because of the mountainous topography of the affected area. Two kind of landslides can be distinguished: (1) The rock and soil fall down slope of weathered and scattered rocks on steeply crest wells observed at Kherrata, Tamrijt, Ouled Moussa, Ziamma Mansouria and likely other inaccessible sites of the epicentral area and (2) The damaging landslide of Laalam studied herein (Fig. 2). Following the main shock of March 20th, 2006, we carried out ground-based field investigation to map the triggered ground deformation. In

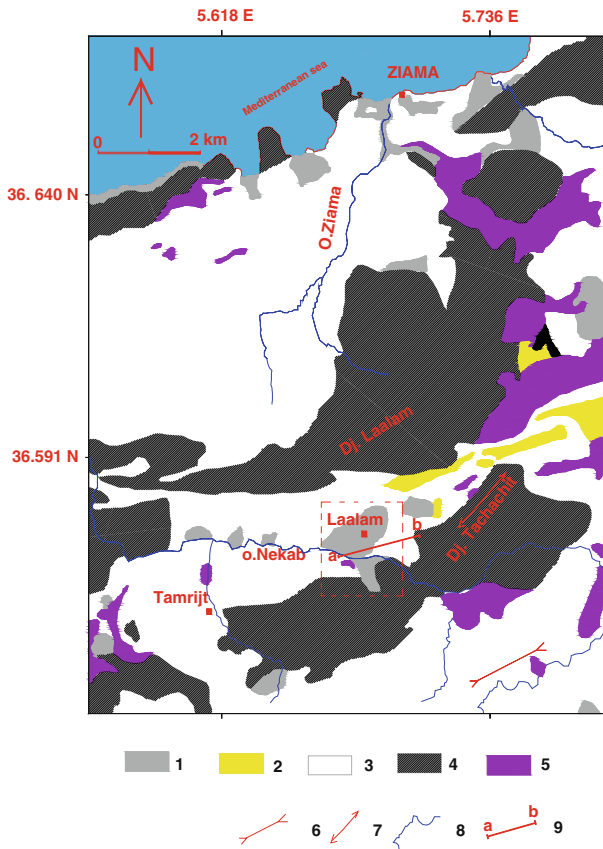


Fig. 6 Geological map of the studied area. 1 = Quaternary, 2 = Neogene, 3 = Cretaceous, 4 = Jurassic, 5 = Trias, 6 = syncline axis, 7 = anticline axis, 8 = river, 9 = cross section of Fig. 7. The dashed square indicates the Laalam site

examining Fig. 8, one may remark a 1-km length sliding rupture striking NE–SW (left side of the landslide). The measured lateral displacement is 45 cm. The rupture plan is dipping 45° with horizontal striations showing the moved block (Fig. 9). Following witnesses, the displacement is released in one time about two (02) hours after the main shock. Cracks can be listened during the aftershock activities but with insignificant displacements (no significant damage added to the affected constructions). Field work allowed us to observe also a 75 cm of pre-2006 lateral displacement likely in relation with past earthquakes. The local witness reminds that the 1974 moderate-sized earthquake activated also this landslide (Fig. 3). Effects of this landslide in the Laalam village are disastrous, it consist of serious damage of housing units, water and waste supply pipelines as well as roads (Fig. 10). The numbered deaths have been caused by collapse of their houses.

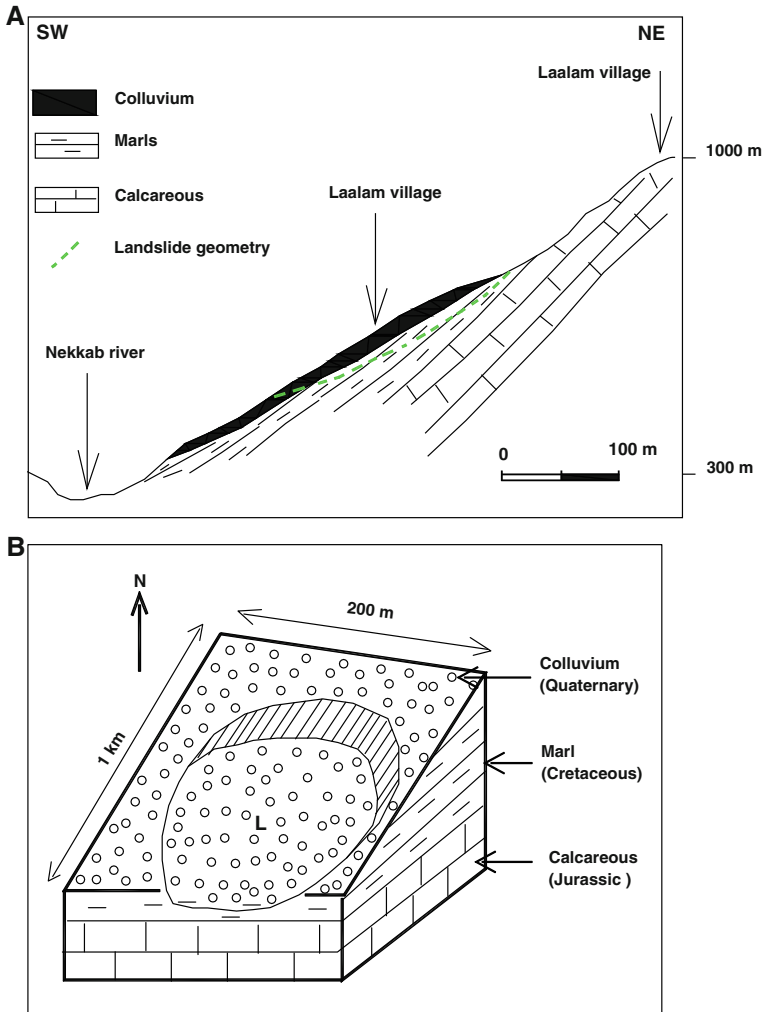


Fig. 7 a Geological cross section of the Laalam site (see *a–b* in Fig. 6). b 3D Scheme of the landslide

4 Discussion and conclusion

The 2006 Laalam moderate earthquake ($M_w = 5.2$) triggered landslides in the epicentral mountainous area, despite its small size, including sparsely distributed rock and soil falls and a damaging landslide which affected the village-dwelling of Laalam. This landslide is the direct cause of the numbered casualties and damage during this earthquake. A total displacement of 45 cm is observed along a 1 km length rupture plan crossing the village of Laalam. This landslide is occurred at 10 km far from the epicenter, hence, comparable to worldwide examples (Keefer 1984) Fig. 11. On the other hand, a pre-2006 trace of the landslide has been observed indicating a repetitive sliding. The last time where this landslide is moved extend back to 1974. It was triggered by the moderate earthquake of

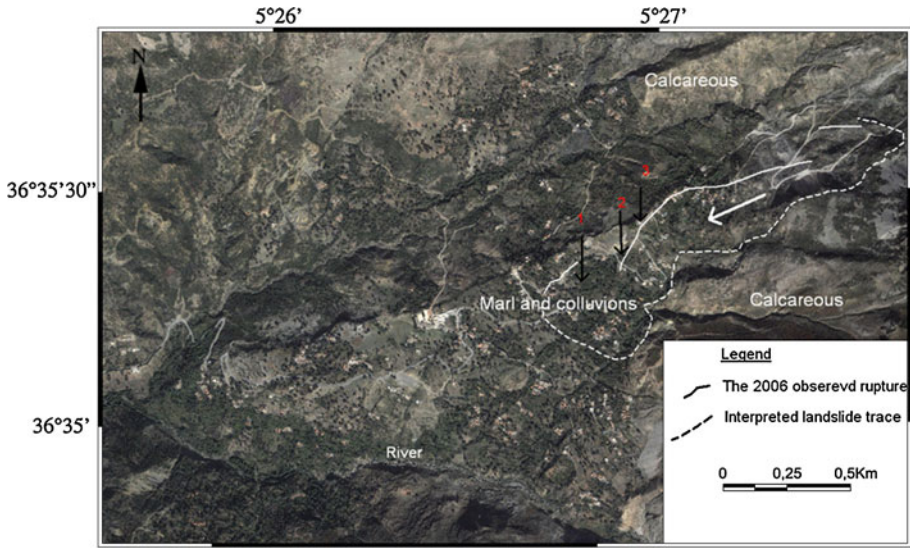


Fig. 8 Satellite image (source: Google earth) of the studied region showing the Laalam landslide. *White arrow* indicates the displacement. *Black arrows 1, 2 and 3* indicate, respectively, the positions of photographs of Figs. 9, 10A, 10D, and 10E

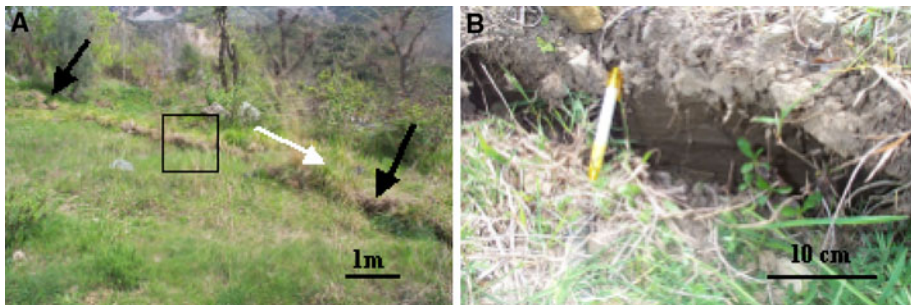


Fig. 9 Ground effect of the Laalam landslide: **a** rectilinear trace of the landslide rupture indicated by the *black arrows*. The *white arrow* indicates the lateral displacement. The *square* indicates detail of the striated plan of the landslide shown in **b**

June 28, 1974 ($I_0 = V$, MSK scale). This landslide did not move during rainy seasons of the last three (03) decades, it is hence typically related to seismic shaking. Two other examples of earthquake triggered landslides has been described in Algeria during this century; The Kherrata (1949) earthquake which triggered a 0.3 m of vertical displacement due to rupture of foothill at 6 km far from the fault on the footwall (Rothe 1950; Gabert 1984) and the El-Asnam 1954 and 1980 earthquakes of magnitude respectively $M_s = 6.5$ and $M_s = 7.3$ which caused a 0.1–1.5 m of vertical displacement at 6.5 km far from the fault on the hanging wall; This latter correspond to extensional secondary faults on the top of the faulted-fold re-activated repetitively in 1954 and 1980 (Rothe et al. 1977; Philip and



Fig. 10 Effect of the landslide on construction and facilities. **a** Outside view of a construction crossed by the landslide rupture indicated by the *black arrows*. **b, c** Inside view of the construction shown on **a** badly damaged; *Arrows* indicate the landslide trace. **d** Non-engineered old construction destroyed by the landslide. **e** A broken water supply pipeline (already repaired)

Meghraoui 1983). The presented example in this work shows how earthquakes-induced ground failure could be disastrous. Indeed, the effect of induced hazards is greater than the earthquake itself in terms of ground shaking.

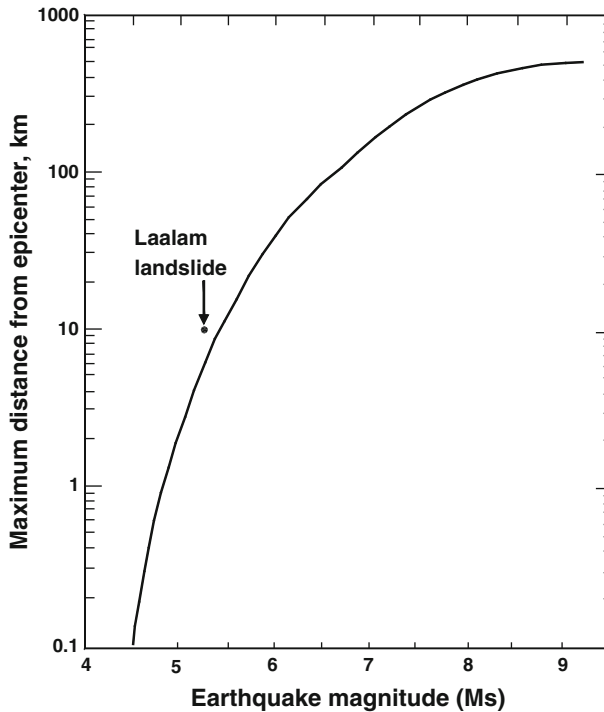


Fig. 11 Maximum distance of landslide from epicenter of 2006 Laalam earthquake as a function of earthquake magnitude, in comparison with other earthquakes based on Keefer 1984

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