# Analysis of the Bejaia Seismic Sequence of 2012–2013, Northeastern, Algeria

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**Abstract**

The Bejaia region in northeastern Algeria experienced three seismic sequences in November 2012, February 2013 and May 2013. The first started on the November 28, 2012, with a main shock of $M_w$ = 5.1. Further, the second has begun on the February 22, 2013, with $M_w$ = 4.3 and was preceded by three foreshocks. Finally, the last sequence occurred on the May 19, 2013, with $M_w$ = 5.2 followed on the May 26, 2013, by an event of $M_w$ = 5.0. Precise relative locations show a cluster of 196 accurately relocated events. The focal mechanisms are consistent with NW–SE striking near vertical right-lateral strike-slip fault, which extends from inland, the Babors chain, to the Gulf of Bejaia offshore on about 30 km long. It is known as the "Kherrata transversal accident," and found to be segmented in four parts S1, S2, S3 and S4, respectively. From the space–time evolution, the rupture seems to have gone through three stages. The area looked like activating an earthquake triggering process which started from S1, migrated progressively to S2, and terminating on S3 and S4. The release of energy has been distributed over four segments of the fault, apparently a disaster was avoided through an earthquake of bigger magnitude. Focal mechanisms, aftershocks distribution, isoseismic maps and the trends of offshore lineaments confirmed the activity of the NW–SE transversal accident, likely responsible for the recent seismicity in the region.

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**Keywords**

The Babors chain • Seismicity and tectonics • Strike-slip fault • Focal mechanisms

## 1 Introduction

The 2012–2013 Bejaia seismic sequence occurred in a moderate seismic activity region spreading from the chains of Babors to the Bejaia gulf. The tectonics of the region is more complicated due to the junction of several seismogenic zones (the Soummam basin, the Lesser and Greater Kabylia) (Fig. 1a). The only detailed seismological study in the region concerns a significant earthquake which has recently affected the Laâlam region, with a moderate magnitude in 2006 (Beldjoudi et al. 2009), which is a property that characterizes all events in the region (see Table and Fig. 1). The characteristics of faulting related to the studied sequence have been revealed through a relative location of events, focal mechanisms, space–time evolution and Coulomb stress variations.

## 2 Seismotectonic Settings

The chain of Babors is located to the North of Setif and East of the Soummam valley. It represents the manifestation of the oblique collision between the tectonic plates of Africa and Eurasia, with local crustal shortening apparent of about 1.5 mm/year (Bougrine et al. 2019). The chain belongs to the external domain of the Alpine belt shown in this area by the Tellian units and embedded between two internal domains of the Lesser and Greater Kabylia (Fig. 1a). The present belt is one of the most seismically active regions, where we highlight the presence of several active faults, particularly the Kherrata thrust fault, known to be active for the earthquake of the February 19, 1949, which generated surface ruptures offset of about 50 cm. This fault has a total


M. Meghraoui et al. (eds.), *Advances in Geophysics, Tectonics and Petroleum Geosciences*,
Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-030-73026-0_32

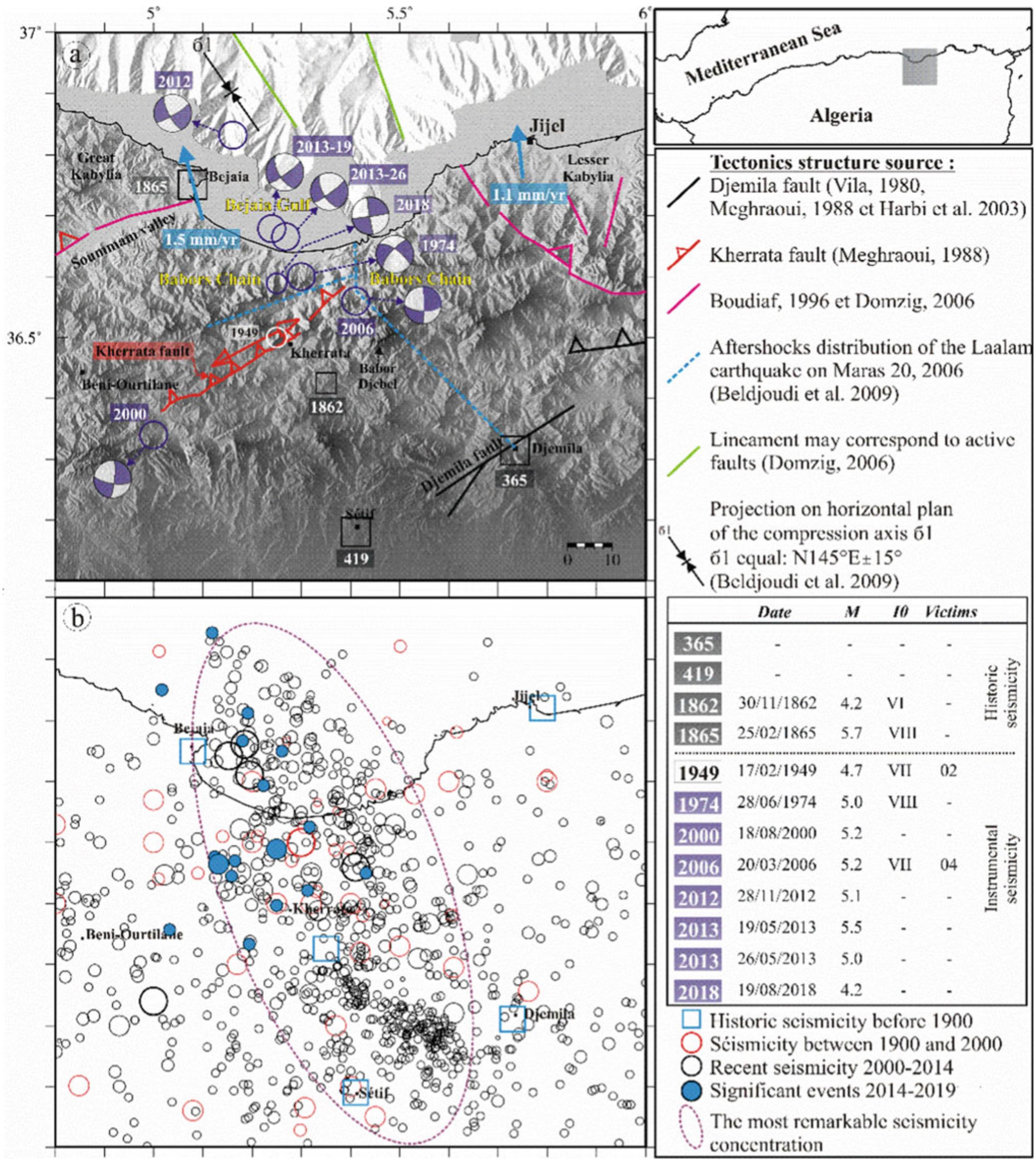


**Fig. 1** **a** Seismotectonic map of Babors zone and Setif region, including GPS velocities from (Bougrine et al. 2019). **b** Seismicity of the region from 1900 to 2014 and significant events during 2014–2019

length of 40 km, oriented N70° with a southward dip (Meghraoui 1988; Rothé 1950). The seismicity distribution (Fig. 1b) shows a cluster oriented along NW–SE, which includes several recent events (e.g., Laâlam earthquake of March 2006), the present studied sequence in Bejaia (2012–2013), and the significant events that occurred between 2014 and 2019. All these earthquakes show a strike-slip dominated movements along NW–SE direction.

## 3 Aftershocks Relocation and Focal Mechanisms' Determination

Applying the widely used HypoDD (Waldhauser and Ellsworth 2000), we relocated 207 earthquakes selected according to both horizontal and vertical uncertainties of less than 2 km. An event must have eight links with neighbors, which is why 95% of the events are kept. The horizontal distribution of the relocated events (Fig. 2a) shows a main cluster, oriented along NW–SE, a fault zone of about 30 km long and 3 km wide. Cross sections A1–A2 and B1–B2 (Fig. 2a) indicate that the foci are distributed on a near-vertical plane, mainly along a band at a depth of 5–11 km. The space–time evolution differentiates three main clusters: C1, C2 and C3 (Fig. 2a, b). It appears that each cluster is likely generated by a segment fault; S1 for C1, S2 for C2, C3 is a V-shaped structure which gives the segments S3 and S4, while all segments belong to the NW–SE Kherrata transverse accident. Focal mechanisms were computed from the first motion polarities using SPHERA (Rivera and Cisternas 1990). The groups of mechanisms are colored and separated according to their appropriate clusters. All focal mechanisms show a strike-slip faulting consistent with right-lateral motion on fault plane, oriented along NW–SE. The mean fault orientation has an azimuth of 136° and it is nearly vertical, in perfect coincidence with the orientation of the whole sequence.

## 4 Discussion

The aftershock data analysis and the focal mechanisms' determination of the 2012–2013 Bejaia earthquake sequences showed a main cluster of 196 accurately relocated events, generated by a NW–SE near-vertical right-lateral strike-slip fault, extending from the Babors Chain to the offshore of Bejaia Gulf for 30 km long. Analysis of the epicenters' locations and the focal solutions of the events that occurred in the region such as: Darguinah 1974, Laâlam 2006, Aokas 2018 and earthquakes between 2014 and 2019, then the trends of isoseismic maps of Laâlam 2006 and Bejaia 2012 earthquakes and finally the offshore lineament identified during MARADJA project lead us altogether to confirm the relationship between this NW–SE fault and the seismicity of the region.

The relocated events exhibited four sub-clusters C1, C2, C3 and C4, probably generated by four fault segments S1, S2, S3 and S4, respectively. The space–time distribution of the seismicity also shows some interesting features as, for two months after the main shock of the November 28, 2012, the aftershocks remained confined along the S1 segment. The area seems to be activating an earthquake triggering process. The triggering process is supported by small variations in the static stress, even lower than 1 bar, which are able to induce the reactivation of nearby faults that are close to failure (Toda et al. 1998). It may involve the generation of aftershocks or major shocks (Stein 1999). The chronological distribution progressively went through the segment S2 to finish on S3 and S4. The preliminary results of the computed Coulomb stress changes do explain the spatial distribution of stress-triggered aftershock seismicity, considering the lobes of high stress increase which perfectly matches the fault segments.

## 5 Conclusions

The Bejaia earthquake sequence (2012–2013) revealed for the first time a new tectonic feature known as the "Kherrata transverse fault," which is likely responsible for the seismic activity of the region. Further, the conclusion by the authors in Beldjoudi et al. (2009) may be incorrect, it cannot be excluded that the 2006 Laâlam earthquake was also associated with a NW–SE direction.

The triggered aftershock seismicity observed during the sequence can have a mechanical implication; fluids may control the space–time evolution of the seismicity, through the non-stationary migration of pore pressure disturbances. When pore pressure slightly increases, the effective Coulomb shear stress increases so that local failure conditions are reached. The role of fluids in the observed seismicity pattern has already been suggested for a few specific cases (Bourouis and Cornet 2009).

The sequence analysis contributes to the knowledge of seismic hazard since the possibility of large slip is not excluded, because the step-over between segments are not exceeding 3 km, taking into account the total width of the fault zone.

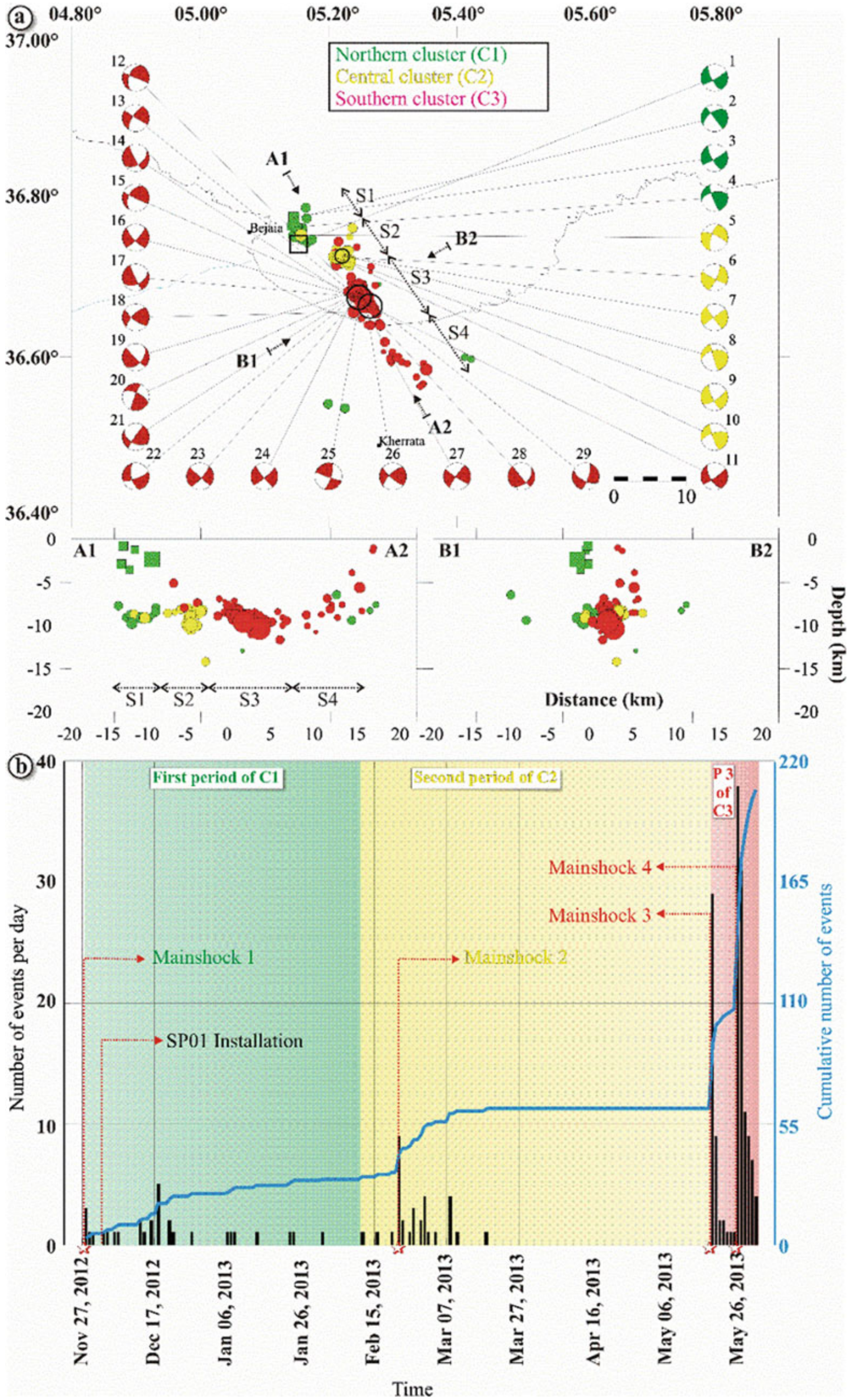


**Fig. 2** **a** Horizontal and vertical distributions of the 196 relocated events, showing focal mechanisms of events with $M \geq 3.0$. **b** Cumulative number of seismic events versus time and number of events per day of cluster 1 (C1), cluster 2 (C2) and cluster 3 (C3)

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