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Constraining recent fault offsets with statistical and geometrical methods: Example from the Jasneuf Fault (Western Alps, France)

Jérémy Billant *, Olivier Bellier, Vincent Godard, Jean-Claude Hippolyte

Aix Marseille Univ, CNRS, IRD, Coll France, CEREGE, Aix-en-Provence, France

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ABSTRACT

We propose two new approaches regarding recent fault offset measurements by studying the seismogenic potential of the Jasneuf Fault.

The NE trending right-lateral strike-slip Jasneuf Fault is the southwestern extension of the Belledonne fault system in the Vercors Massif. This fault, which is located in an intraplate domain, does not show strongly associated seismicity but displays morphological anomalies that are related to recent faulting (right-lateral offset of Late Cenozoic cliffs, recent talwegs, and post Günz scarps).

The two methods that we use to quantify fault slip are as follows. 1 - Recursive measurements of stream offsets are conducted. This analysis reveals that a stream network can display characteristic distances between streams that can be mistakenly interpreted as long-term cumulative fault offsets. A comparison of the apparent stream offset values and stream spacing values is necessary to identify the true offsets. 2 - We propose a new method that enables us to determine the fault offset and kinematics by using recursive measurements of topographic apparent offsets to counter the lack of morphologic features that are used to determine piercing points or lines. This method enables us to define each possible slip vector for numerous artificial piercing points along a fault. The slip vector that is shared by these piercing points is the true slip vector.

By applying these methodologies, we determine that the Jasneuf Fault has accumulated slip since the Messinian, which corresponds to an average slip rate of 0.13 ± 0.03 mm year^{-1}. The extension of the fault is poorly constrained. Nevertheless, if we do not consider the potential aseismic (creep slip) component of the faulting, we calculate that this fault could generate Mw 5.7 earthquakes every ~500 years according to Wells and Coppersmith's scaling laws and by assuming that the faulting is limited to the sedimentary cover and the Vercors Plateau.

1. Introduction

Although intraplate settings are generally characterized by low strain rates, these regions can be struck by destructive earthquakes (e.g., the 1356 Basel Earthquake, Switzerland, Fäh et al., 2009; the 1811–1812 New Madrid earthquakes, United States, Tuttle et al., 2002; the 1909 Lambesc earthquake, France, Baroux et al., 2003; Chardon et al., 2005; Lacassin et al., 2001; the 2001 Gujarat earthquake, India, Rastogi, 2004). A direct consequence of these low strain rates is that the recurrence intervals between destructive earthquakes can reach several millennia. Thus, historical seismicity cannot document an entire earthquake cycle. Moreover, the combination of these low strain rates and unfavorable climatic conditions may leave few offset markers and thus complicate morphological analysis.

This study focuses on the NE-trending Jasneuf Fault in the western French Alps, which present the above-mentioned features and whose seismogenic potential is unconstrained. The Cléry and Jasneuf fault zones are located at the southwestern end of the right-lateral strike-slip "Belledonne border fault" (Fig. 1), which was seismically defined by Thouvenot et al. (2003). These fault zones are included within the Belledonne fault system.

High-resolution topographic data have revealed a morphologically well-expressed fault trace, but classic morphological markers that are used to constrain fault offsets are poorly preserved or absent, which complicates the quantification of offsets. We use talweg offset measurements and compare these values with recursive measurements of the talweg spacing to compensate for this lack of markers. Usually, only the apparent offsets can be measured when typical morphologic

* Corresponding author.
E-mail address: billant@cerege.fr (J. Billant).

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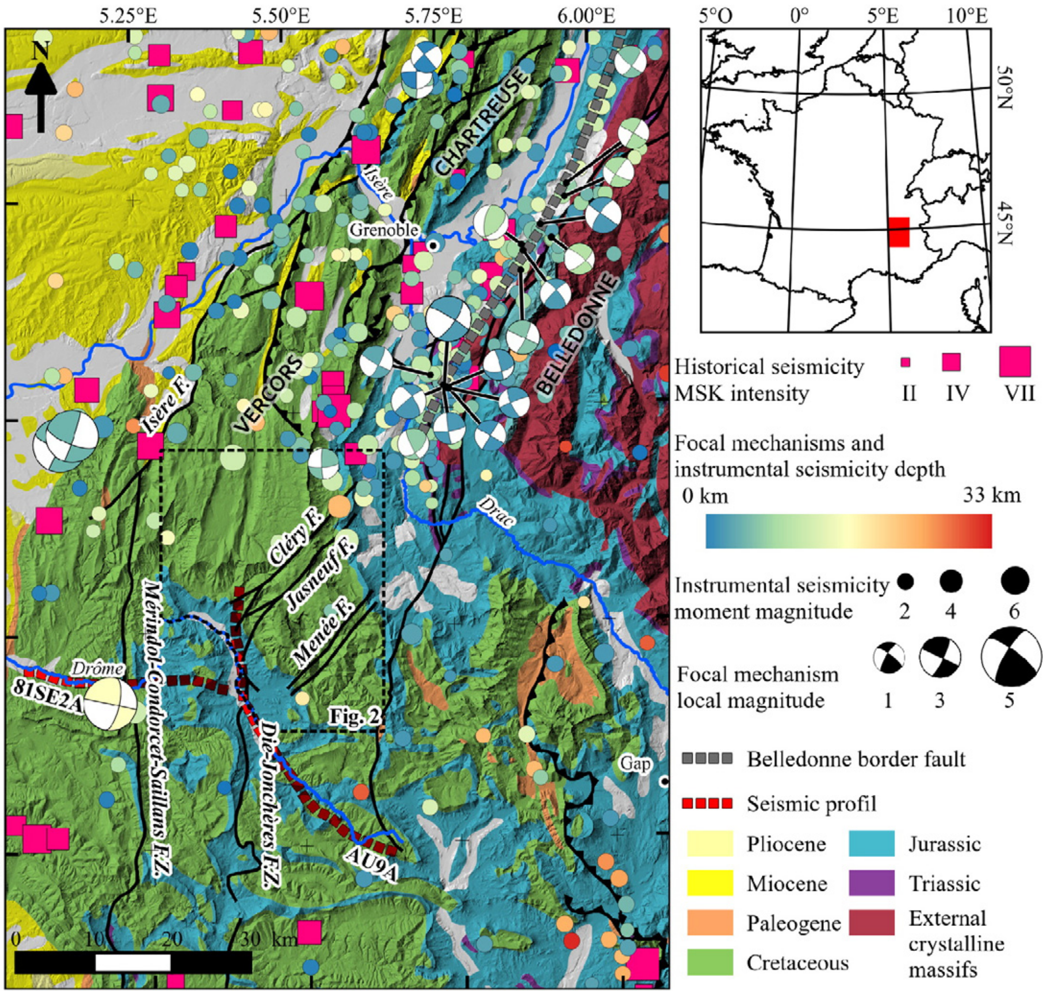

Fig. 1. Simplified geological map (Bodelle and Goguel, 1980) and seismicity of the region, which includes the study area. The historical seismicity is from the SISFRANCE catalog (Scotti et al., 2004), the instrumental seismicity is from the *Si*-Hex catalog (Cara et al., 2015), and the focal mechanisms are from Ménard (1988), Nicolas et al. (1990) and Thouvenot et al. (2003).

markers (e.g., streams, fans, or moraines) are lacking. We demonstrate that we can determine the true fault offset by recursively measuring these apparent offsets, and we present a method to perform such an analysis.

2. Geological framework

The Vercors Massif is a thin skinned fold-and-thrust belt whose formation began during the Miocene with the thrusting of the external crystalline massif (Butler, 1987; Philippe et al., 1998). The Cléry and Jasneuf fault zones, which cut the southern highlands of the Vercors Massif, are underlined by approximately 6-km-long linear step escarpments (Fig. 1). Both fault zones affect the wide and flat Glandasse Plateau. The geology of this plateau consists of approximately 200-m-thick Barremian limestones that overlap approximately 1000-m-thick Barremian marl series (Arnaud, 1966; Arnaud et al., 1974). In this area, the sedimentary cover is 6–7 km thick (Bellahsen et al., 2014; Le Pichon et al., 2010; Philippe et al., 1998), the Moho depth is 37–38 km (Ménard, 1979), and the lower and upper crusts are ~10 km and 27–28 km thick, respectively (Ménard and Thouvenot, 1984).

Arnaud et al. (1974) proposed that the Cléry and Jasneuf Faults extend northeastward to the Belledonne Massif. According to these authors, the Cléry Fault may connect southwestward with the Mérindol-Condorcet-Saillans fault system, whereas the Jasneuf Fault may connect with the Die-Joncheres fault system (Fig. 1). Therefore, the Cléry and Jasneuf fault systems could reach ~52 km and ~34 km, respectively. In fact, both faults affect marly rocks outside the calcareous Vercors Massif (Debelmas et al., 1967; Flandrin et al., 1974), which implies that their morphologies are not well expressed in such highly erodible deposits. Both faults split into multiple segments at the southwestern termination of the Glandasse Plateau (Figs. 1 and 2).

The total right-lateral offsets along the Cléry and Jasneuf Faults are 3.5 km and 3 km, respectively, as suggested by the lateral offset of the southern limit of the lower Barremian detrital limestones (Arnaud, 1981; Robert, 1976) and the difference in shortening between two parallel finite geological sections on both sides of the Cléry Fault (Thibaut et al., 1996).

Studies of the fault network by aerial photographs (Arnaud, 1971; Robert, 1976) provided evidence of fractures that are organized into a Riedel system, with the average direction of the right-lateral faults ranging between N030°E and N080°E. Normal dip slip and/or low lateral component slip faults have directions that range between N080°E and N105°E, and left-lateral faults trend between N105°E and N160°E. Finally, reverse and thrust faults trend NNW to NNE (from N160°E to N210°E). Clear markers of brittle deformation (fault planes with polished surfaces and cataclastic rocks) in limestone and markers of pressure-dissolution ductile deformation in the underlying marl have been described along the Cléry Fault (Gratier et al., 2013; Thibaut et al., 1996).

The Jasneuf and Cléry Faults are located at the southwestern end of the right-lateral strike-slip "Belledonne border fault" (Fig. 1), which was seismically defined by Thouvenot et al. (2003). Unlike the "Belledonne border fault", the Cléry and Jasneuf Faults do not display associated seismic activity, except where earthquakes occurred at their