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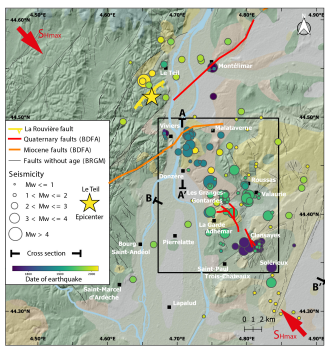
Laurent Bollinger¹, Kristel Le Dortz^{1,2,3}, Clara Duverger¹, Amaury Vallage¹, Sylvie Marin¹, Yves M. Leroy²

¹-CEA, DAM, DIF, 91297 Arpajon, FRANCE (contact : Laurent.bollinger@cea.fr)
²-Ecole normale supérieure, Department of Geosciences, PSL Research University, Paris, France
³-now at Seister, 40 Avenue de Lascours 13400 Aubagne, France

1. Abstract

The Tricastin region, in the lower Rhône Valley (France), is affected by an atypical seismic activity characterised by the development of long-lasting and recurrent seismic swarms. Indeed, since the 16th century, hundreds of seismic events sometime associated with underground noises of explosion have been reported by local inhabitants. However, to date, none of the many scenarios of earthquake generation proposed for the area, involving either tectonics and/or hydrological forcings, appears consensual. To overcome that lack of comprehension, we compile and analyse a 880 seismic-events catalogue derived from both historical macroseismicity and instrumental records (Figure 1 to 6). The earthquakes appear occurring at shallow depths (Figure 6) possibly similar to those determined below a local network in 2002-2003 (Thouvenot et al., 2007). We confront to this catalogue models involving hydrological mechanisms, including aquifers elastic loading and karst-drains responses, as well as tectonic mechanisms, including transient aseismic processes and their related effects on the fold hinges or on the local fault planes (Figure 7-8 and Table 1). Most of the earthquakes are located at short distances from karst drains and fractured fold hinges, possibly affected by transient hydrological changes.

Figure 1: Simplified geological and seismicity map of the Tricastin region. Historical and instrumental seismicity (circles, coloured according to their date of occurrence) from FCAT17 catalogue (Manchuel et al., 2018) complemented with the LDG catalogue (Duverger et al., 2021). Many other historical events were felt by the population but they are not recorded in the database because no epicentre were determined. See Figure 2 for further information about the location of every swarm compared to the geological structures, as well as the paleocourse of the Rhône River and tributaries. Geology and faults in black are from the BRGM 1:1000000 geological map and field observations. Faults in red and orange are from the Base de Donnée de Failles potentiellement Actives (BDFA), the Database of Potentially Active Faults (Jomard et al., 2017). Cross sections AA' and BB' are reported on figure 6. Yellow star and thick line respectively for Le Teil earthquake epicentre (from seismological records and InSAR) and fault surface rupture. Red arrows represent the orientation of the Maximum horizontal stress (SHmax) from Heidbach et al., 2018.



2. Seismotectonic setting

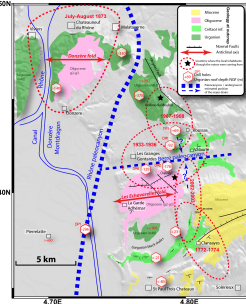


Figure 2 : Close up view on the geology of the north-eastern part of the Tricastin region showing up: two major anticlinal structures in red arrows (the Donzère fold to the North, and the Echavannes fold to the South); the position of the Messinian paleocanyons in thick blue dashed lines; the depth of the roof of the Urganian in drill hole in red hexagons. Thick red dashed ellipses represent the approximate location of the seismic swarms derived from the macroseismic documentations. The black stars correspond to the locations where the local inhabitants though the noises were coming from.

3. Data collection

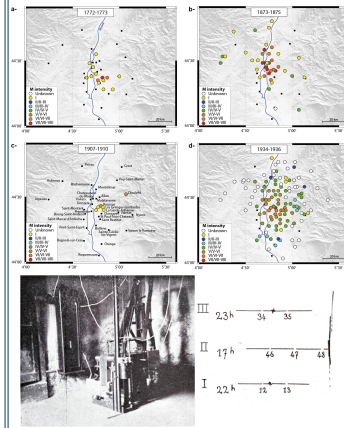


Figure 3 : Maximum intensities observed in the Tricastin villages for a) 1772-1773 b) 1873-1875 or 1876 c) 1907-1910 and d) 1934-1936 crises. Intensities are from the SisFrance database and interpreted in MSK64 scale. The yellow circles for intensity I correspond to events that were felt but for which no intensities were assessed. White circles for intensities 0 correspond to non-felt events and are only available for the 1933-1936 crises for which macroseismic forms were sent to the local administrations by the Bureau Central Sismologique Français (BCSF).

Figure 4 : Left: Mainka-Som seismograph at Les Granges-Gontardes. Right: example of seismic signals recorded at the station in 1934

4. An atypical time structure

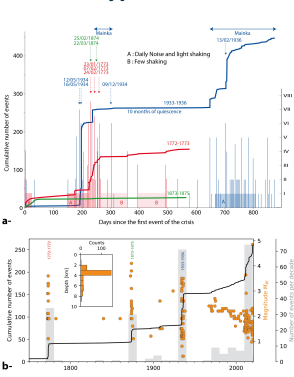


Figure 5 : a)- Cumulated number of seismic events for the 1772-1773 (red curve) and 1934-1936 (blue curve) crises, starting from the first event of each crisis (sources: SisFrance, 2021; Faujas de St Fond (1783) and Rothé, 1936, 1939a). The double arrows correspond to the period of operation of the temporary Mainka-SOM seismographs installed by the BCSF in Les Granges-Gontardes (Figure 4). The thin lines represent the most important events for which an internal intensity has been determined or interpreted from archives. b)- Cumulated number of seismic events (black curve) in FCAT17 catalogue (Manchuel et al., 2018) complemented by the LDG catalogue from 2010 (Duverger et al., 2021). The plot starts in 1750 for a better visual appreciation of recent years, but 6 events are reported before, starting in 1173. The right-axis presents the moment magnitude (M_w) of the events (orange circles) and the number of events per decade in the catalogues (grey bars). The inset is the depth histogram of events.

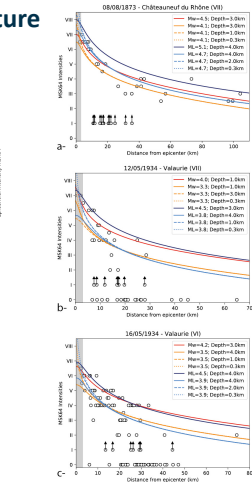


Figure 6 : Comparison of observed and predicted intensities for the 08/08/1873 -Châteauneuf-du-Rhône, 12/05/1934 and 16/05/1934 -Valaurie earthquakes. Observed MSK1964 intensities are from SisFrance (2021) and predicted MSK1964 intensities for different magnitudes (colored curves) are obtained using Marin et al. (2004) attenuation lawand Baumont et al. (2018) IPEs, respectively in ML and in Mw. An empty circle with arrow means that the event was felt but no intensity determined. The observed intensity I might thus be equal to II or greater. The intensity distribution is consistent with shallow hypocentral depths, according to the predicted intensity attenuation deduced from the attenuation law. The grey band corresponds to a range of distances outside the domain of validity of Marin et al., 2004.

5. Models

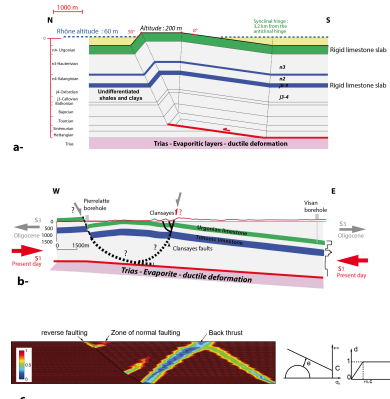


Figure 7 : a) Schematic North-South cross-section of the Donzère anticline, interpreted as a fault-propagation fold. b) Schematic East-West cross-section of the Tricastin, through Clansayes and the Echavannes anticline modified from Gratiot et al. (2013). c) Distribution of the scalar of the distance to the Coulomb criteria varying from 0 (dark blue) to 1 (dark red). The right plots show the definition of the distance to the Coulomb criterion (e) and of the scaled distance to the criterion (d). When $d=1$, e is more than 1% of the cohesion, far from the failure criterion, while when $d=0$, the Coulomb criterion is satisfied.

Table 1. Calculations of the Coulomb stress variations (ΔS) resulting from the changes in water thickness. These calculations have been done 1/ on fault planes similar to the post-Oligocene fault planes observed in the field, and 2/ on the preferential rupture planes deduced from the examination of the regional stress field from focal mechanisms, taking a friction coefficient of 0.6.

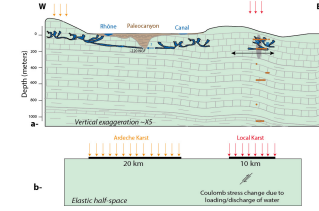


Figure 8 : Schematic West-East cross-section of the Tricastin region (vertical exaggeration of 5). a) A schematic karstic network is drawn in dark blue. Orange dots correspond to the depth distributions of relocated earthquakes from the 2002-2003 crisis at (from Thouvenot et al., 2009). The Rhône paleocanyon is represented in brown and the present Rhône River and canal in blue. b) and c) illustrate the input parameters of the models.

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