

# A triggered seismic swarm below the city of Strasbourg, France on Nov 2019

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## Introduction

On 12 November at 2.38 pm (local time), a felt earthquake of magnitude 3.0 MLv took place near Strasbourg, France (in the Robertsau area) at a depth of 5km (Fig. 1).

Very quickly the question of the link between this earthquake and a human activity arose because of its proximity to the Geoven deep geothermal site (5km), operated by the company Fonroche-Géothermie in the commune of Vendenheim, a few kilometres north of the Robertsau area.

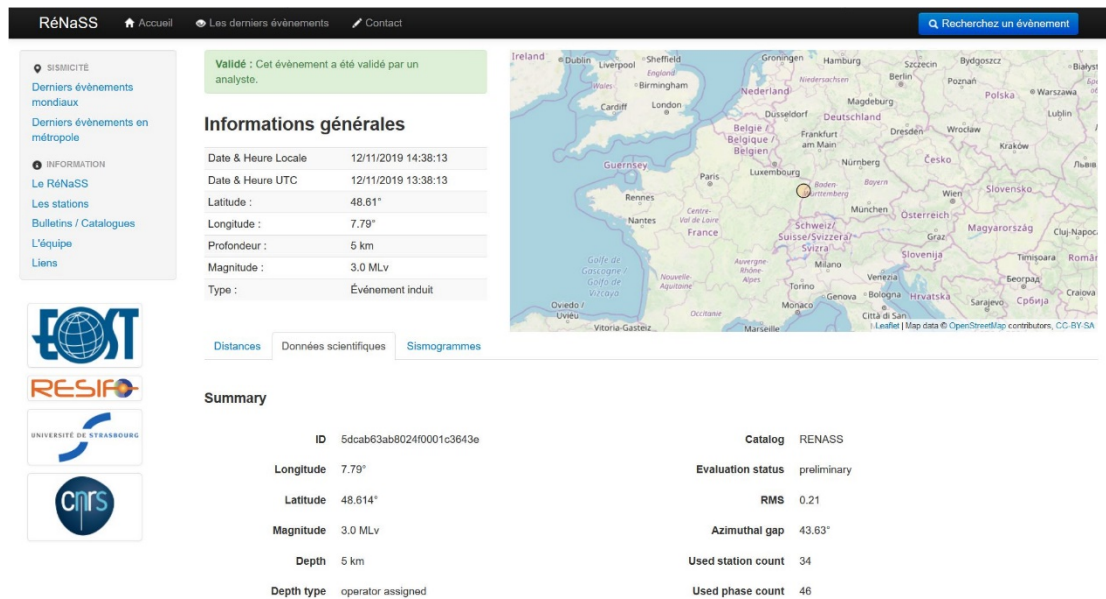


Figure 1: Identification of the M<sub>l</sub>3.0 magnitude event of 12 November 2019 from the RéNaSS/BCSF website (3/2/20)

Figure 2 shows the seismological networks used to locate events from 2018 to 2020 in the area. The main stations used are located within a radius of 80km around the epicenter of the M<sub>l</sub>3.0 earthquake of 12 Nov 2019 (about 76 stations). Seismological data comes from: a) regional networks, both national (RLBP, RAP) and international (Germany, Switzerland, Luxembourg); b) an experimental Raspberry Shake network from EOST; c) Fonroche public local network.

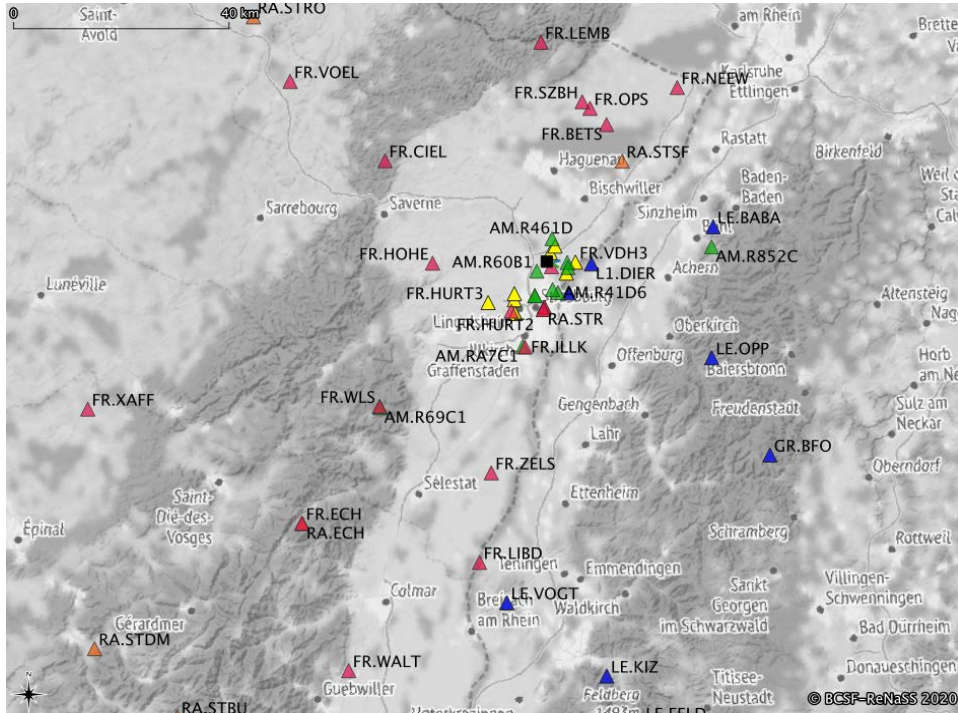


Figure 2: Location of the 76 seismological stations used in this study on the scale of the Rhine graben. Colour code of the stations (triangle): red: permanent RLBP stations (velocimeters); orange: permanent RAP stations (accelerometers); yellow: permanent stations of the Fonroche-Géothermie company; green: temporary EOST (RaspeberryShake) stations; blue: temporary German LGRB stations (L1 network), permanent LGRB stations (LE network) and permanent GRSN stations.

## Two seismic clusters

The main earthquake of November 12 is part of a seismicity cluster of more than a hundred micro-earthquakes, located at a depth of about 5km on a fault zone and 4.6km south of the GEOVEN wells (Fonroche company) (see Fig. 3, in red).

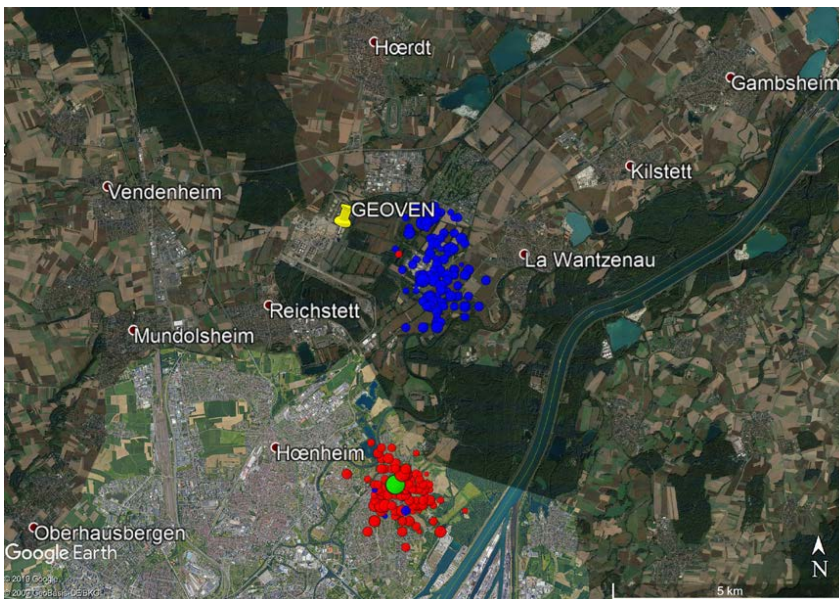


Figure 3: Location of micro-earthquakes according to the RéNaSS catalogue on 31/01/2020, during the period from 14 March 2018 to 31 January 2020 (241 events) in a 6km region centred on the epicenter of the 12 Nov 2019 earthquake (in green). In yellow, location of the GEOVEN wellheads (Fonroche company); in blue, the micro-earthquakes between 14 March 2018 and 11 November 2019; in red, the micro-earthquakes after 11 November 2019 until 31 January 2020. A 5km scale is shown on the bottom right of the figure.

In this "southern" cluster, activity increased sharply on the morning of 12 November and continued for nearly 3 months with events of generally decreasing magnitude over time, but with resumption of activity in particular around 6 December 6<sup>th</sup>, 2019 and January 10<sup>th</sup>, 2020 (see Fig. 4), behaving as a seismic swarm.

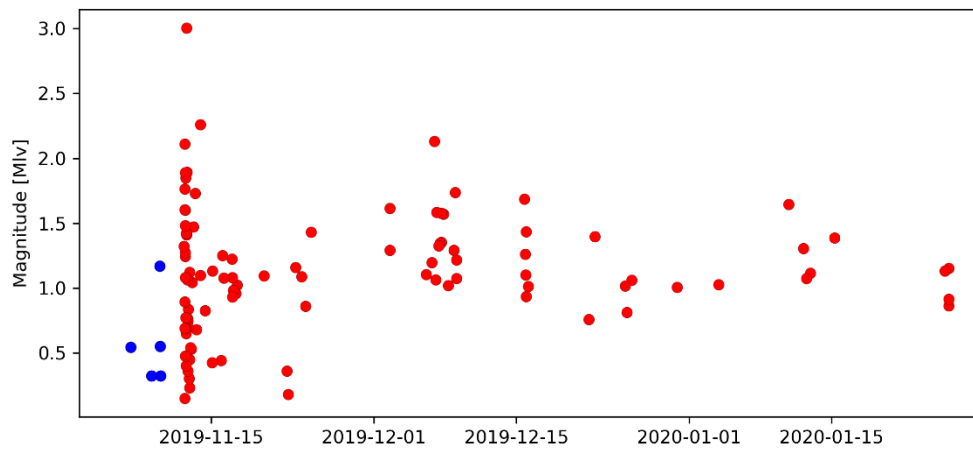


Figure 4: History of seismicity within a perimeter of 2km around the epicenter of the M3.0 earthquake of Nov 12, 2019 (according to the RENASS catalogue of 31/01/2020). The reference day is 12/11/19 at 0h. In blue are the 5 earthquakes recorded before 12/11/19. In red are the events between 12/11/19 and 26 Jan 2020 for the last ones.

During this period, the "northern" cluster (associated with the hydraulic testing of the GEOVEN wells), gradually became extinct (Fig. 3, in blue). However, earthquakes were observed there until 24 January 2020, i.e. nearly 80 days after the end of the on-site hydraulic tests.

The study also identified using template matching more than 800 new micro-earthquakes since March 2018 when drilling operations were initiated. They occurred both during periods of activity in the boreholes of the deep geothermal site, but also between these periods. Some of these earthquakes have been finely relocated (double-difference relative location) to image in detail the fault structures in each cluster.

A search for possible precedents in regional historical seismicity (1980- 2019) was carried out. Only one similar case was found: a 25-day sequence after a magnitude 3.3 earthquake northeast of Sélestat in November 2005 on a regional fault bordering the Rhine Graben.

## A triggered seismic swarm

The occurrence of so-called "triggered" earthquakes (i.e. triggered directly or indirectly by human activities) of low magnitude in the environment close to boreholes is common, particularly during the hydraulic stimulation phases of a geothermal reservoir, as is the case for the "northern" cluster (e.g. Zang et al, 2014; Grigoli et al, 2017; Goebel and Brodsky, 2018).

Here, it appears to be both a temporal and a spatial correlation between the seismic activity of the two zones.

- **Temporal correlation (Fig. 5):** From the night of 6 to 7 November 2019, the "southern" seismic swarm developed 4km south of the Vendenheim site, which corresponds to the end of a phase of hydraulic tests on the GEOVEN wells. This analysis confirms that the phases of activity of the two seismic clusters overlap at the beginning of November, showing the temporal correlation between the end of the activity on the GEOVEN site, the "northern" cluster, and the start of the "southern" swarm.

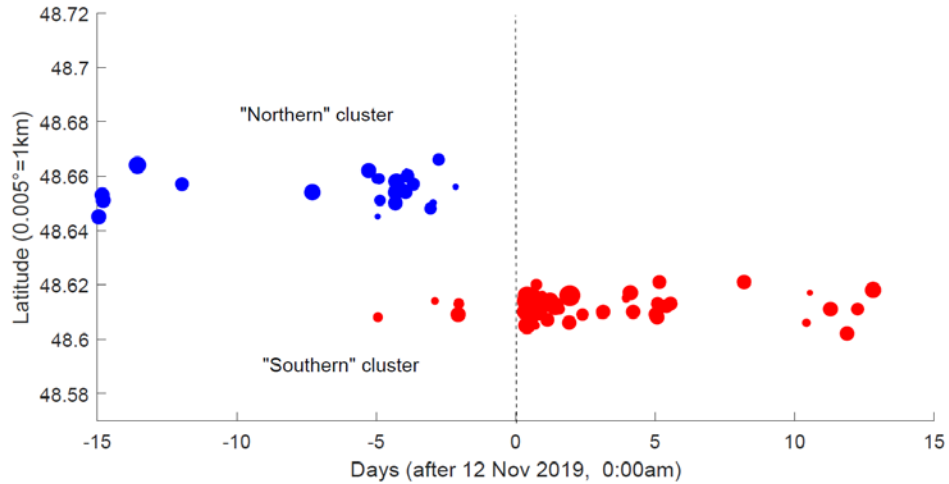


Figure 5: Temporal evolution of seismicity 15 days before the event M13.1 of 12 Nov 2019 (RéNaSS catalog). In blue, the events of the 'northern' cluster, in red, those of the 'southern' cluster. The size of the circles is proportional to the magnitude of the event.

- **Spatial correlation (Fig. 6):** The spatial link between the two clusters over a significant distance (4.6 km) can be explained by : a) the presence and the orientation of the Robertsau fault that connects the two swarms; b) a strong structural link between the two zones, demonstrated by the similarity in depth of the two clusters; c) the existence along this fault of a mechanical situation close to instability due to the particular orientation of the fault in relation to

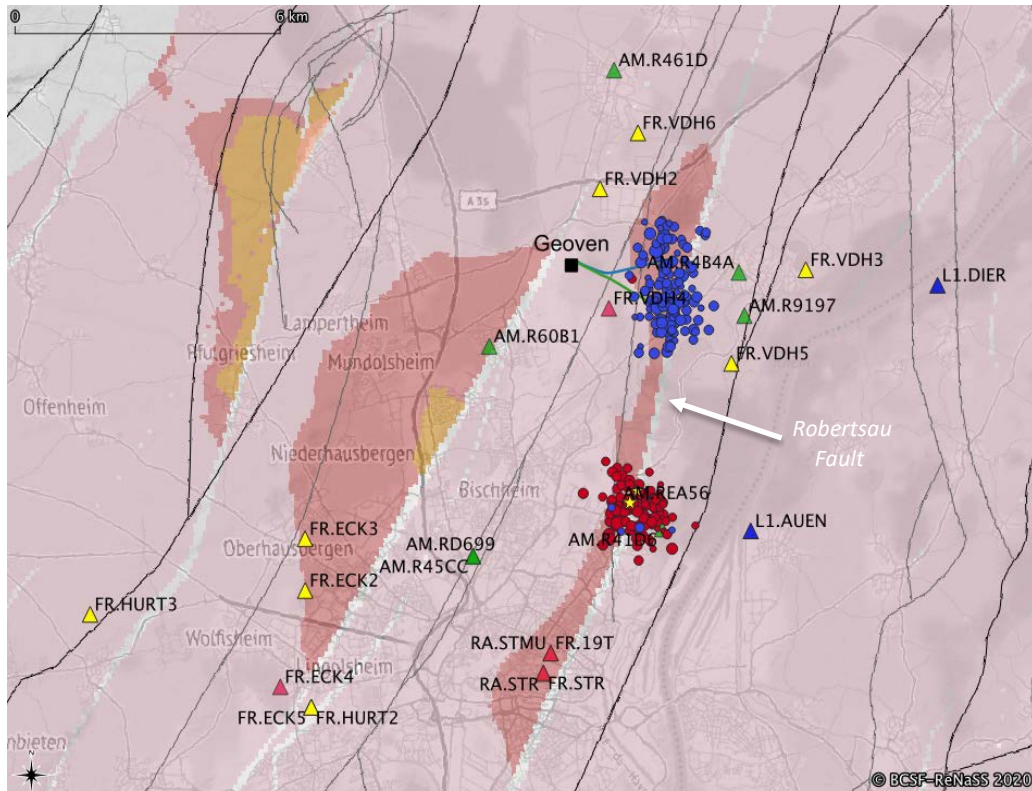


Figure 6: Location of the "northern" and "southern" seismicity clusters from the RéNaSS catalogue (dated 31/01/2020) in relation to the local structural geology. In blue, the earthquakes before 12/11/19, in red those after. The 2 main earthquakes of 12 Nov (M<sub>l</sub>v 3.0) and 13 Nov (M<sub>l</sub>v 2.3) are marked by yellow stars in the "southern" swarm. The seismological stations are indicated by triangles, the color of the triangles representing the network to which the station belongs. The position of the GEOVEN wells is represented by the green lines. The colored background represents the geology at a depth of 4km (extracted from the GEORG database: <http://maps.geopotenziiale.eu>). In black are shown the position of the main faults on the surface and in white their position at 4000m depth. The earthquakes are globally at a depth of about 5km. The two clusters "northern" and "southern" are located on the same fault (Robertsau fault) with an orientation of about N10.

the regional stress field. Failure in the “southern” swarm can therefore be triggered by very slight variations in stress, such as those induced by overpressure during fluid injections into deep wells, even several kilometers away.

## Conclusion

On Nov 12, 2019, a M<sub>l</sub>v3.0 earthquake was felt by the whole population of the city of Strasbourg, France. It was located by the BCSF-RéNaSS (EOST) in the northwestern part of the town (Robertsau area) at a depth of 5km. The event is part of a seismic swarm that was initiated at least six days before the main shock and lasted more than two months. We show that several key features like its location in the vicinity of the deep geothermal wells (GEOVEN) where a long term induced seismicity has been recorded, the temporal correlation with the injection activity on site, the similarity of the depth between the bottom of the wells and the hypocenter of the event, the lack of local seismicity before the event occurrence, the known geological structures including a regional critically-stressed crustal fault connecting the “Northern” and “Southern” clusters, confirm the possible triggering of the “Southern” seismic swarm by the deep geothermal activities despite the relatively large distance (4-5km).