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 MLv3.0 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 MLv3.0 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.
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).

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 6th, 2019 and January 10th, 2020 (see Fig. 4), behaving as a seismic swarm.
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.
• **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...
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 Mlv3.0 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).