Ground vibrations caused by geothermal drilling operations: a case study from the Rittershoffen EGS project (Alsace, France)

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ABSTRACT

Since 2012, the micro-seismicity activity of both Rittershoffen and Soultz-sous-Forêts geothermal projects has been monitored by a permanent seismological network composed of 12 surface stations, completed by 31 temporary stations during and after the drilling the 2nd well of the Rittershoffen project. This densely spatially distributed seismic network allowed to measure the level of vibration in terms of velocity displacement at each site during and after the drilling phase. The frequencies of the noise vibrations caused by drilling operations are included in range of [2-20] Hz. In that frequency range, the increase of vibration noise generated by drilling operation is not distinctive from the vibrations measured during a reference time period at stations beyond 1 km away from the drilling platform. However, some specific spectral rays have been identified (i.e. 25.05 Hz or 29.84 Hz) that can be detected at least up to 5 km away from the drilling platform. For these frequency rays, the propagation of the vibrations shows anisotropy, with a preferred direction of propagation southwards. Globally, vibrations caused by drilling operations were below the human being perception threshold.

1. INTRODUCTION

Designed to produce 24 MWth (170°C, 70 l/s) with a doublet, the Rittershoffen EGS project is located 6 km eastwards of the well-known Soultz-sous-Forêts EGS project, in Northern Alsace, France. The first well, GRT-1, reached its final depth of 2580 m MD end of 2012 for targeting local normal-faults located at the interface between the clastic Triassic sandstones and the top crystalline basement. Numerous logs and hydraulic tests were performed beginning of 2013 and it has been decided to develop the permeability between the well and the reservoir. A reservoir development strategy has been performed and the results were positive, since the injectivity of the well was multiplied by a factor of five (see Baujard et al 2015, Maurer et al 2015, Recalde Lummer et al 2014).

The second well, GRT-2, was drilled from March to August 2014 using a HH300 drilling rig. This machine is able to hang 270 t and was used to drill a deviated well of 3200 m length down to 2707 m TVD depth. After the drilling phase, production tests and circulations tests were performed. No reservoir development was required since production tests revealed that the initial productivity index was sufficient for developing an industrial project (Baujard and al 2015).

Since some induced seismicity was expected during the reservoir development of GRT-1, the permanent seismic monitoring network has been reinforced with a temporary short-period surface network. In total, 31 short-period stations were installed in a range of 5 km around the drilling platform from the very beginning of the drilling of GRT-2. These stations remained installed till November 2014. They remained deployed after the production tests, so five months after the end of the drilling phase.

Since 2012, the micro-seismicity activity of both Rittershoffen and Soultz-sous-Forêts geothermal projects has been monitored by a permanent seismic network composed of 12 surface stations:

- The Soultz seismic network is composed of short-period (1 Hz) seismometers, one or three components (L4C/L4C 3D), deployed at surface. Signals are digitized on site by 15-bit GEOSTAR data loggers and sampled at 150 Hz. The signals are then transmitted to a central site via a radio link where samples are synchronized with an external time receiver (DCF). At the central site, a SeisComp3 plugin fetches the GEOSTAR formatted data and makes it available through SeedLink to Strasbourg University (EOST), via an internet connection.

- The Rittershoffen seismic network is composed of short-period (1 Hz) three components seismometers (L4C 3D), deployed at the surface. Signals are digitized by Quanterra Q330S directly in miniSEED format at a sampling rate of 100 Hz, increased to 200 Hz by beginning of 2014, and are sent to a central site via a Wifi connexion. Here a SeisComp server makes data available to the

Strasbourg University (EOST) via internet. Unlike the Soultz network, this architecture prevents from data losses in case of transmission failures since the data are always available at the server installed in the field.

In addition to this permanent network, a temporary network was deployed in two steps. First of all, 16 real-time telemetered surface stations were deployed in order to monitor the stimulation operations of the first well GRT-1. Secondly, 15 non-telemetered surface stations were deployed in March 2014 to further densify the existing network before the drilling of GRT-2 and in prevision to the reservoir development. The whole temporary network is composed of three-component seismometers (L4C-3D) and EarthData loggers (PR6-24, old generation), sampled at 300 Hz. Details concerning the temporary network of the KIT can be found in Gaucher et al 2013. Finally the GRT-2 reservoir was not developed, but the monitoring of the drilling of GRT-2, as well as the production and circulation tests delivered a high quality dataset. It offered a better coverage and a better sensitivity than for the first well stimulation. The main objectives of this network were first the development of semi-automatic micro-seismic characterization techniques based on dense networks, and secondly, to perform a reservoir tomography based on the noise induced by the drill-bit during the drilling of the second well GRT-2 (Gaucher et al 2013).

This densely spatially distributed seismic network (see Figure 1 for locations) allowed to measure the level of vibration in terms of ground velocity at each site during and after the drilling phase.

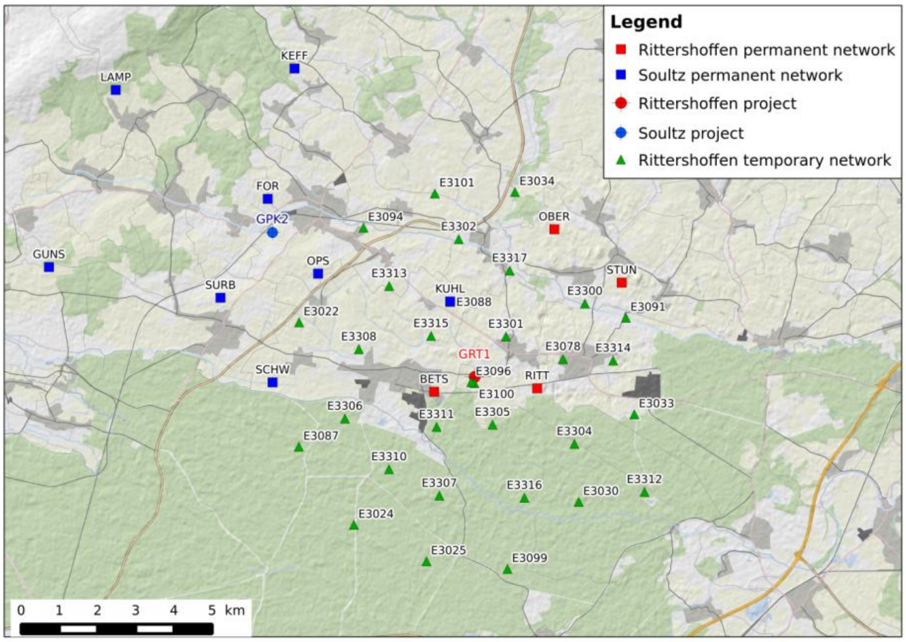

Figure 1 : location of the permanent and temporary seismological stations

2. METHOD

In order to measure the vibrations induced by the drilling, the following methodology was applied: The seismic signals were first corrected from the instrumental response. The Power Spectral Densities (PSD) of the hourly noise records were then computed on the vertical component of all the stations installed in a radius of 5 km around the platform. From those PSD measurements, we evaluated the frequency range attributable to the drilling. The temporal evolution of the PSD computed using the vertical component of station E3100 (installed on the drilling platform, close to the source) is shown on Figure 2

The seismic signal related to the drilling period appears clearly at frequencies between 2 and 20 Hz and is more pronounced at the beginning of the drilling. As the vibrations caused by the drilling itself are difficult to distinguish from all the surface operations (pumps, power generators, vibrating tables,…), the source analyzed in this paper is the global vibration caused by the drilling operations. To be noticed, the hydraulic production and tracer tests generated a seismic signal at frequencies between 30 and 100 Hz with a peak above 50Hz, which is higher than the frequency of the drilling signal. The later operations also caused a source at about 0.8 Hz.

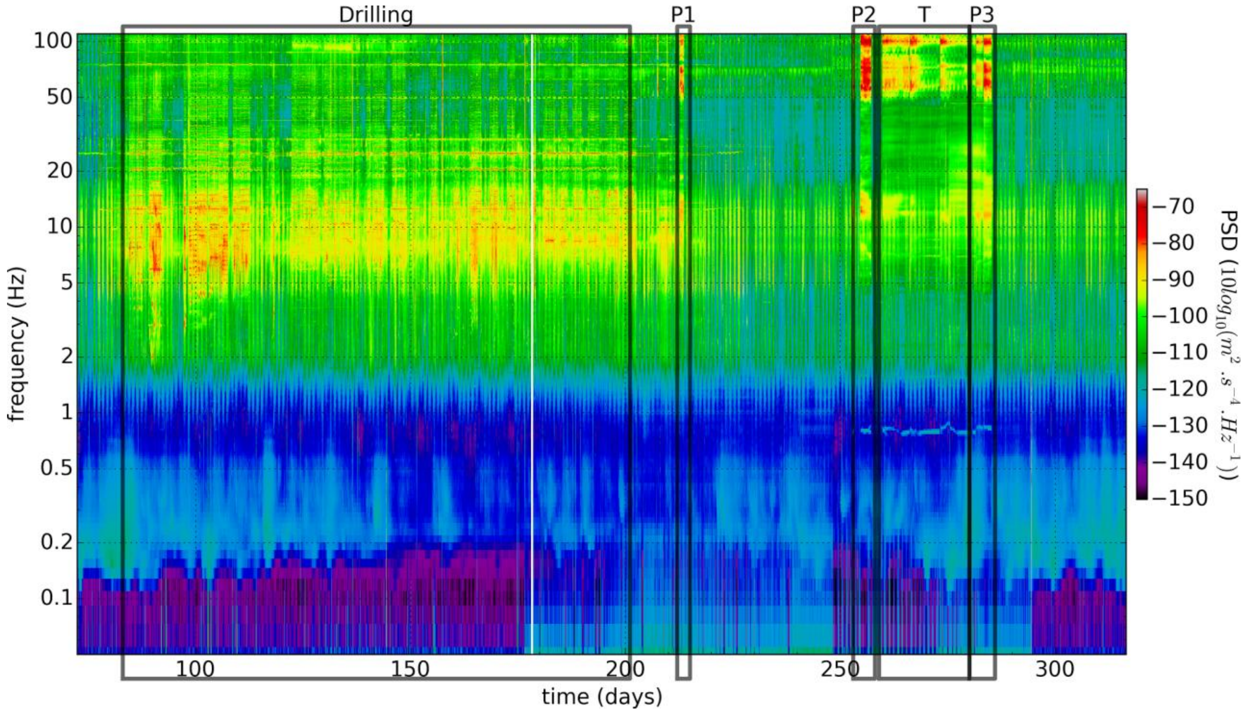

Figure 2 : Spectrogram of the vertical component of station E3100 installed on the drilling platform. The abscissa corresponds to the time axis expressed in julian days of year 2014 and the ordinate is the frequency expressed in Hz. The color represents the power spectral density (PSD) expressed in 10log ($m^2.s^{-4}.Hz^{-1}$). The black boxes delimitate the different operations performed on the drilling platform. P1, P2 and P3 denote production tests. T stands for a tracer test conducted between the two wells.

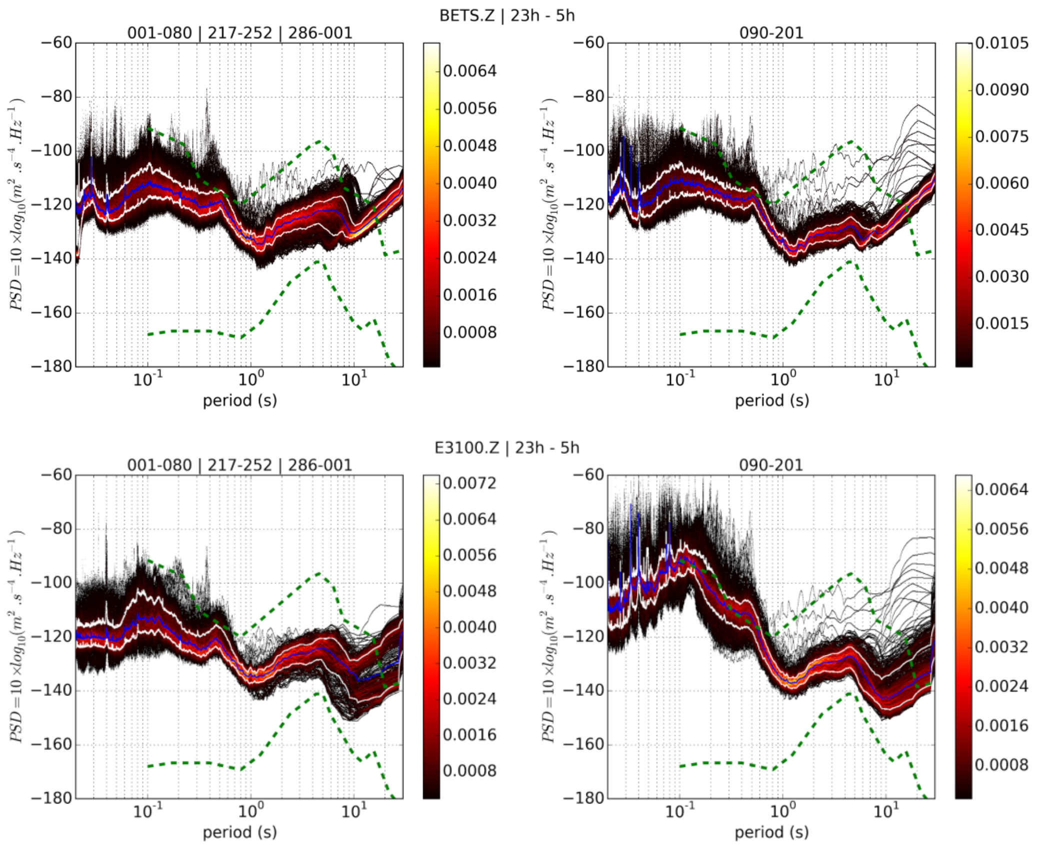

Figure 3 : Probability density function of the PSD computed during the drilling periods (right side) and during the reference period (left side) at stations BETS (top) and E3100 (bottom). We only use the noise recorded between 23h and 6h, local time. The color bar corresponds to the probability density. The blue lines represent the median PSD. The white lines correspond to the 16% and 84% percentiles of the PSD distribution. The green dashed lines indicate the low and high noise models from Peterson 1993.

From this spectrogram, we defined a "reference" period of time during which, no drilling or production tests were conducted on the platform: it includes days 1 to 80, 217 to 252 and 286 to 365. The "drilling" period was taken between days 90 and 201 (see Figure 3).

As the reference period covers a broad time span over the year, it is representative of the annual variations of the ambient seismic noise, like seasonal noise variations (winter/summer) or anthropic noise variations (working/vacations periods). In the frequency band of interest [2-20] Hz, the daily anthropogenic noise is strong, which masks part of the signal induced by the drilling. To minimize that effect, only night hours from 23h to 6h were considered.

3. RESULTS

By analysing the statistical variations of the PSD, we derive a median PSD at each station for both the reference and the drilling periods (see Figure 3). The difference between these two median PSD is calculated at each station (see Figure 4). In the [2-20] Hz frequency band, the cumulated gap is calculated and shown on a map (see Figure 5).

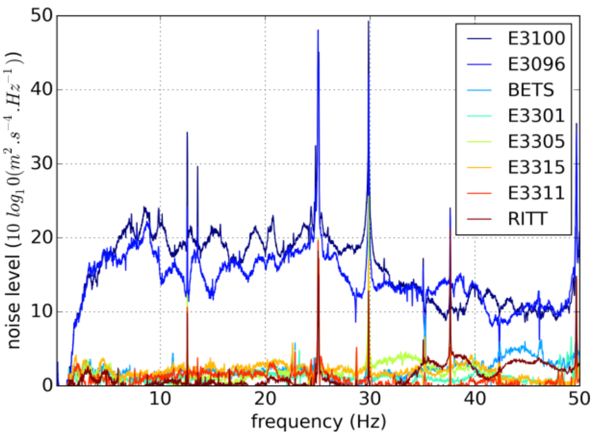

Figure 4 : Differences between the median PSD of the reference time and the drilling period measured at the 8 stations the closest to the drilling site. Stations E3100 and E3096 were located on the drilling platform

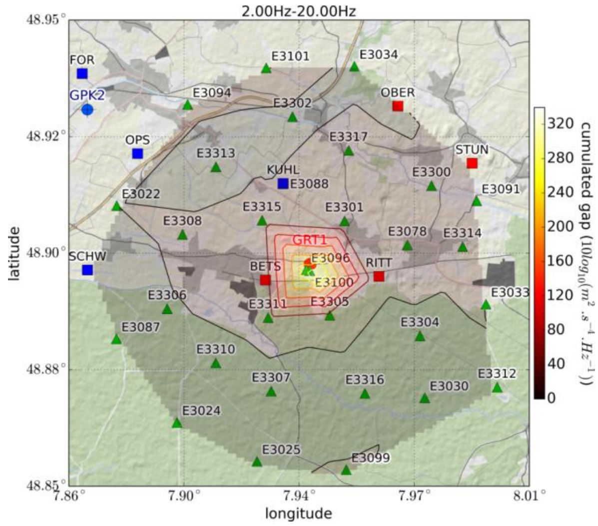

Figure 5 : Map of the cumulated gap between the median PSD of the reference time and the drilling period in the [2-20] Hz frequency band

In the [2-20] Hz, the two stations installed on the drilling platform are clearly emerging from the other stations. However, even for the closest stations to the drilling platform, located at about 1 km away, the cumulated gap between the reference time and the drilling period is not clear, except for certain specific spectral rays (for example 25.05 Hz or 29.84 Hz) that are clearly coming from the drilling platform. The Figure 6 shows a map of that difference for the spectral ray observed at 29.84 Hz.

Even if the origin of this source is clearly caused by the drilling operations, the source itself has not been clearly identified yet (pumps, vibrating tables, resonance of a structure,…). This signal is prominent on the two stations installed on the drilling platform and drops rapidly. However it can be observed a few kilometers away from the platform and especially to the south. This pattern might be caused by a lower level of anthropogenic noise in the forest making the drilling signal more detectable in that zone. It could also be caused by a heterogeneity of the propagating medium. The vibrations caused by the drilling rig is thus perceptible by short-period sensors at least up to 5 km away from the drilling platform, but without being perceptible by the population.

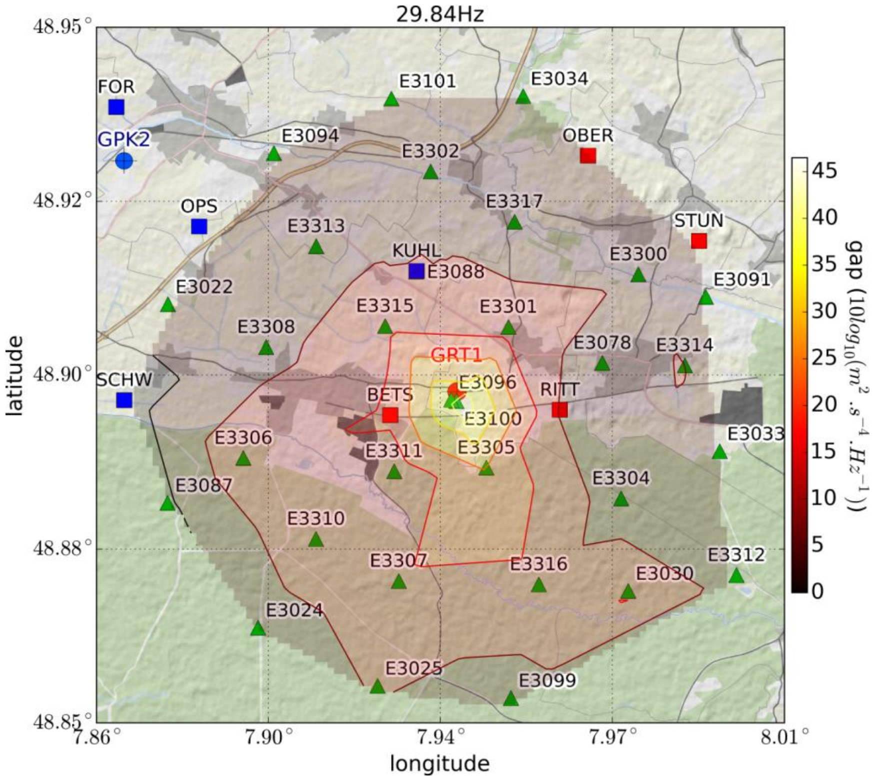

Figure 6 : Map of the gap between median PSD of the reference time and the drilling period for the spectral ray observed at 29.84 Hz

4. CONCLUSIONS

This work allowed quantifying the level of vibration caused by a drilling operation in terms of ground velocity, which represents an acceptability issue for implantation of geothermal projects, especially in urbanized areas. Indeed, it is a recurring issue during public inquiries asked by French administration for drilling allowance. In this study, we showed that the noise vibrations caused by drilling operations are included in the frequency range [2-20] Hz. In that frequency range, the increase of vibration noise generated by drilling operation is not distinctive from the vibrations measured during a reference time period at stations beyond 1 km away from the drilling platform. However, some specific spectral ray have been identified (i.e. 25.05 Hz or 29.84 Hz) that can be detected at least up to 5 km away from the drilling platform. For these frequency rays, the propagation of the vibrations shows anisotropy, with a preferred direction of propagation southwards. Globally, vibrations caused by drilling operations were below the human being perception.

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