European Geothermal Congress 2019
Den Haag, The Netherlands, 11-14 June 2019

# Upper Rhine Graben: the largest exploration by 3D seismic reflection

Alexandre Richard[1], Éric Gillot[2], Vincent Maurer[1], Nicolas Cuenot[1], Johanne Klee[1]

[1] ES-Géothermie, 5 rue de Lisbonne, 67300, Schiltigheim

[2] CGG Services, 27 Avenue Carnot, 91300, Massy

alexandre.richard@es.fr

**Keywords:** exploration, 3D seismic reflection, EGS, Rhine Graben, wireless, wide azimuth, acceptability, project management.

## ABSTRACT

As Électricité of Strasbourg is owner of 3 contiguous exclusive exploration licenses (over 400 km²) and 2 concessions (40 km²) for deep geothermal projects in Northern Alsace (France), a large 3D seismic campaign covering an area of 180 km² and partially overlapping these licenses, (Figure 1) has been acquired during summer 2018 in order to get a detailed litho-structural image of the sedimentary cover of the basin and to apprehend in 3D the geothermal reservoir.

34 years after the last large-scale 2D seismic campaign (1984), this acquisition survey in the Upper Rhine Graben will benefit from all geophysical technology developments that have occurred since then.

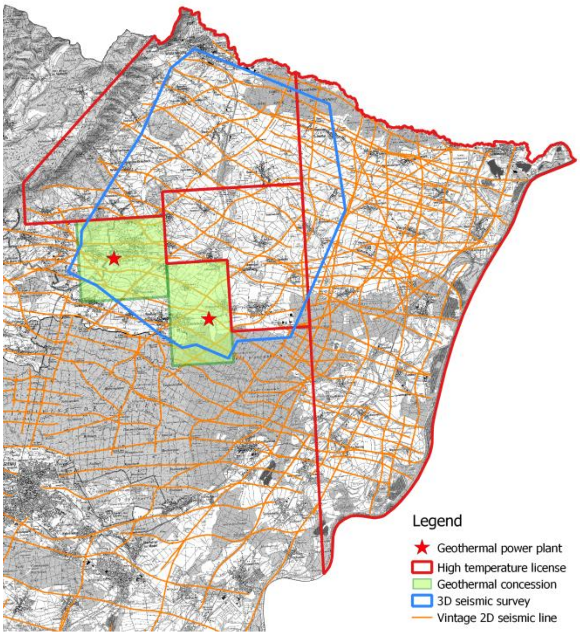

**Figure 1 : Regulatory and geophysical context of the 3D seismic exploration survey in Northern Alsace. (Source ESG)**

In particular, broadband seismic ranging from 2 Hz up to 96 Hz delivered by 62 000 lbs vibrotrucks and 27 000 vibrated points in a wide azimuth acquisition geometry might be major breakthroughs in order to reach the geothermal target, constituted by permeable faults crossing both sedimentary layers and crystalline basement.

The paper will develop the initial feasibility study, the selected acquisition/equipment parameters, the operational aspects of the project and finally first processing results.

## 1. From feasibility study to survey planning

To successfully complete this project, which is the second largest 3D seismic survey in metropolitan France, a preparation work of several months was carried out a year ago.Firstly, an in-depth analysis of the vintage 2D seismic parameters and results (acquired in 1975 and 1984) was conducted in order to have a *a fortiori* characterization of the ground response in the area of interest. These elements made possible to constrain the upper limit of the sweep to 96 Hz. The lower limit of the sweep has been set at the limit of the hydraulic and mechanical capacity of vibro trucks (2 Hz).

In a second step, a draft mapping of the whole Northern Alsace was made in order to locate the areas of strong land constraints, the distribution of population, crops, transport networks and all other elements of infrastructure that may make such an acquisition difficult or impossible (Figure 2).

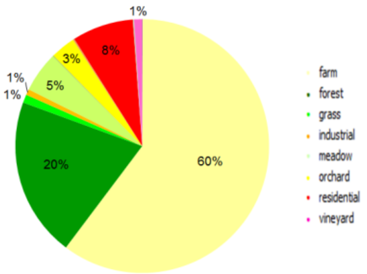

**Figure 2 : Statistical repartition of land use within the exploration area. (Source ESG)**

To these elements of surface mapping were added knowledges of the subsoil and in particular the structures of the Upper Rhine Graben (URG) deduced from previous seismic exploration and geothermal wells drilled respectively at Soultz-sous-Forêts and

Rittershoffen. As the preliminary study did not reveal any major surface constraints, the boundaries of the 3D seismic footprint (Figure 1 and Figure 3) were therefore established to the West by the edge of the so-called "Soultz horst", to the East by the beginning of 2 major listric faults deepening the geothermal target, to the North by the French-German border and finally to the South by the Haguenau forest.

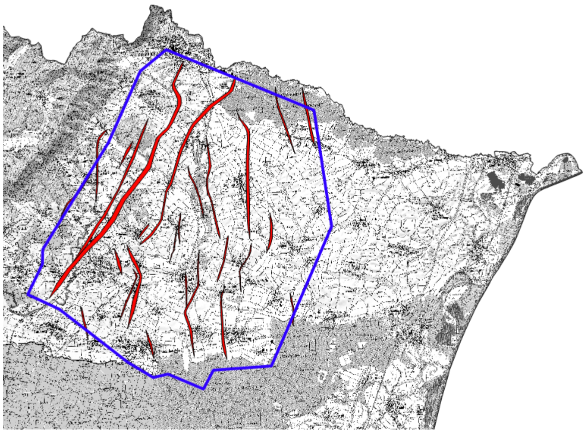

**Figure 3 : Seismic survey in regard of the known geological structures of the URG. (Source ESG)**

The acquisition geometry is of course a compromise between the imaging objective, the possibilities granted by the field and the financial budget allocated to the project Considering depth of the target, the basement-sediment (Buntsandstein) interface has a strong spatial variability and ranges from 1400 m to more than 3000 m depth. Since this interface is difficult to visualize and to interpret on vintage seismic data, the Buntsandstein depth map illustrates this variability (Figure 4).

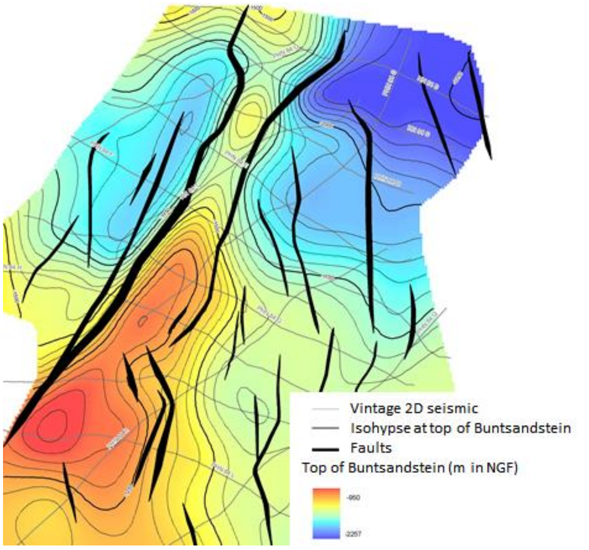

**Figure 4 : Top of the Buntsandstein varying from 950 m to 2260 m depth in the area of the 3D seismic survey. (Source ESG)**

Statistics on the distribution of roads and paths in Northern Alsace have shown a distance of about 500 m along the East-West axis. This length was considered too large to be retained as spacing between source lines and was therefore reduced to 320 m. The inter-line and inter-trace also impacting the cost of the mission were set respectively at 200 m and 40 m (Table 1 and Table 2).

**Table 1: Description of acquisition geometry.**

| | Distance (in m) | Number |
|---|---|---|
| Crossline | 320 | 41 |
| Receiver line | 200 | 88 |
| Receiver spacing | 40 | 22 600 |
| Source spacing | 20 | 27 000 |

**Table 2: Technical description of deployed equipment.**

| | | |
|---|---|---|
| Sweep | [2-96] Hz | Single 48s sweep / VP |
| Vibrator | M26 / AHV | Up to 10 active vibs |
| Sensor 1 | UNITE | 20 000 |
| Sensor 2 | WTU | 3 000 |
| Geophones | SG-10 | 6 per string |

Although the linearity of receiver lines was maintained as much as possible, it was not possible to require the same consistency for the source lines. Indeed, due to heavy costs expected for crop compensation, the vibe paths were designed to avoid entering fields, using in priority roads, tracks and field boundaries (Figure 5).

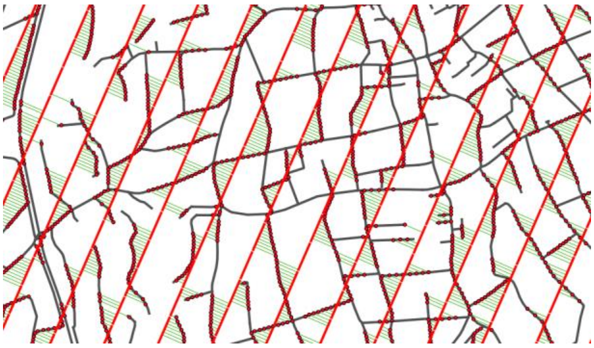

**Figure 5 : Deport map of source point positions from theoretical grid to operationally feasible geometry. Red line was the initial 320 m crossline geometry deported (green line) to final positions (red points) on roads (gray line). (Source ESG and CGG)**

As 42 municipalities were located over the area of the survey, it was not possible to overcome a passage in their close vicinity and even in their center without risking seismic coverage lost (Figure 14). To obtain all the authorizations, a qualification in terms of vibratory emission was carried out in order to fix the safety distances with respect to houses. The digital cartography of all infrastructures (water, gas, sanitation, etc.) made it possible to accurately define the position of the 8 000 VPs inside cities.

Finally, the last and exhaustive part of this preparatory work concerned permitting aspects that alone can ensure the success or disaster of a project of such a scale. A very significant cartographic work consisted of identifying all the farmers impacted by the project, geo-referencing their agricultural parcels, indicating the contact details and the type of crop sown on their farmlands (Figure 6).

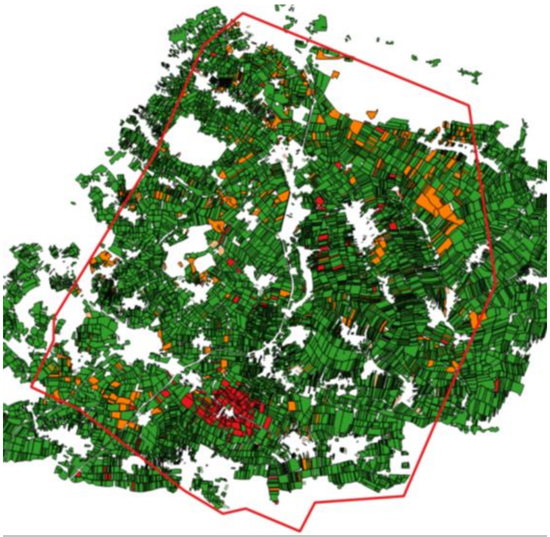

**Figure 6 : Map of farm lands within the 3D seismic survey (red polygon). Authorized accesses are shown in green, refused or not crossable in red and orange parcels need prior contact.**

## 2. FIELD OPERATION

### 2.1 Vibroseis

Due to field constraints, two types of vibrators were used. One with soundproofing (Figure 7) was used in villages and forests and heavier ones were used in open field (Figure 8). A single vibe, single sweep (duration of 48s) acquisition design was selected accordingly to the SRS (Simultaneous Random Sweep) solution. The choice was made to double the source density (20m between VPs) as compared to the receiver density (x6 10Hz geophones and 40m between RGs) for production efficiency.

**Figure 7: AHV-IV (deployed number: 1) - Peak force output 275 kN (62 000 lb).**

**Figure 8: Mertz 26HD-623B (deployed number: 9) - Peak force output 276 kN (62 000 lb).**

### 2.2 High productivity technology

The acquisition technologies used in Alsace, known as SRS and EmphaSeis$^{TM}$, is a vibroseis high-productivity acquisition technique derived from the Oil & Gas industry's latest advances made in Middle East (Denis *et al*., 2013).

#### 2.2.1 Pseudorandom sweeps

With SRS, the common time and distance separation shooting rules, known as particularly stringent using standard O&G high-productivity techniques (blending) don't exist anymore, allowing unprecedented degree of freedom and productivity.

Vibrators operate independently and are not synchronized from the recorder system anymore. Sweeps are not emitted at specific time slots or with distance-separation. Each of the 10 vibrators emits a dedicated encoded sweep when ready at its position. As vibrators shake when they are ready, it is mandatory to record data in a continuous mode.

The encoded pseudorandom sweeps (Sallas et al., 2011) are designed in such a way that they can overlap, and even be emitted at the same time by various vibrators. The SRS technology has the ability to successfully separate the resulting mixed signal so that it is free from interference. The source separation is performed in the field through multi-source deconvolution using the permanently recorded ground forces (instead of the sweep pilot used when performing the traditional correlation).

#### 2.2.2 Broadband sweeps

EmphaSeis$^{TM}$ (Saleh et al., 2017) broadband technology is a sweep method that extends the frequency bandwidth of vibroseis data. It is performed by using the vibrator mechanical and hydraulic specifications to optimally design the output force and the variable sweep rate, without any risks for the quality of the sweep or the mechanical systems of the vibrator. This ensures the maximum possible drive level at each frequency (Tellier and Ollivrin, 2019) (Figure **9**). The customized nonlinear sweeps are designed to build up energy at low and high frequencies while keeping in the vibrator operating well within its capabilities.

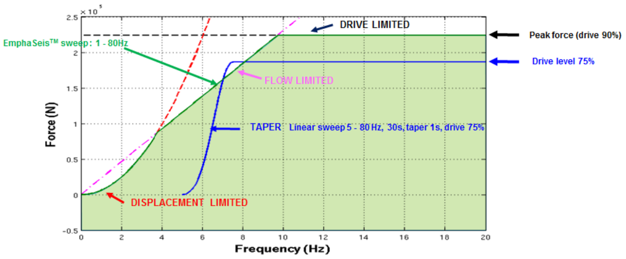

**Figure 9: Comparison between EmphaSeis$^{TM}$ broadband sweep and conventional linear one.**

Once converted into the SRS encoded sweep, potentially harmful resonant frequencies are eliminated, allowing closer safe access to buildings and underground infrastructure.

### 2.3 3D designs transition: from WAS0 to WAS1.

The initial 3D design was based on 30 receiver lines (Figure 12) for a 9 000 channels active spread.

**The survey started from north the 16th of August 2018. Decision for a summer time acquisition was taken in order to operate between end of wheat harvesting (July) and before corn silage (October). Unfortunately due to exceptional summer conditions (hot and dry) silage of corn occurred earlier than planned by the end of August, simultaneously over the whole survey area (**

Figure 10).

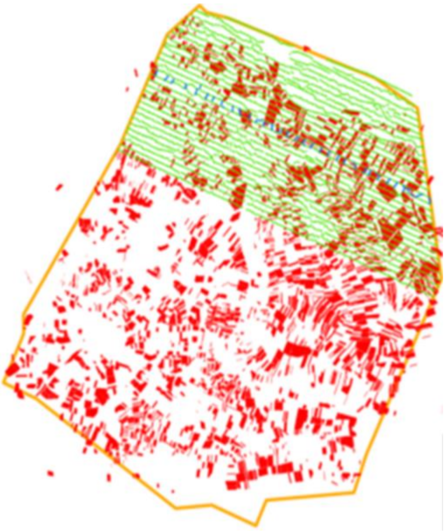

**Figure 10: Location of corn fields (red polygons) across the survey area. (Source CGG)**

Apart from noise on the spread due to up to 40 silage teams working simultaneously in the fields, the immediate consequence was the obligation to remove Unite / WTU and geophone strings already layed out in corn fields to avoid their destruction by harvesting machines. The daily targeted layout was 1 200 receivers (3 swathes per day). Many “farmer crews” (dedicated harvesting/QC team for farmers issues) were necessary to cope with this unexpected situation, removing the stations before harvesting and shifting them to the nearest safe position or relocating them at the initial position after harvesting of corn. Some days it was necessary to move up to 900 stations!

As a consequence and to be able to continue the acquisition, decision was taken to bunch the 6 geophones and to crunch corn in a circle pattern to allow harvesting without removing equipment in the field (Figure 11).

**Figure 11: Layout of 6 geophones bunched traces in corn field to allow corn harvesting while recording. (Source Google Maps)**

A change of survey strategy was decided to minimize the impact on productivity and data quality. Decision was taken to shift from WAS0 to WAS1 operation (Figure 12), reducing by half the number of receiver lines (30 to 15) and in parallel repeating every VP position twice on different spread. 27066 single VPs and 17151 doubled VPs were recorded. The switch from 30 receiver lines to 15 lines has been gradually organized in seven days (Figure 12).

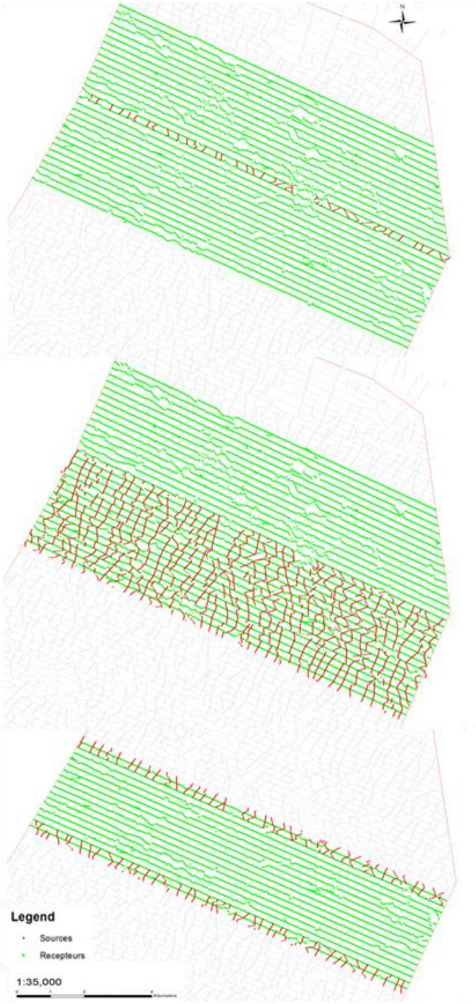

**Figure 12: Transition from 30 WAS0 active lines (top), intermediate swath (middle) to switch to a 15 active lines WAS1 swath (bottom). (Source CGG)**

## 3. QUALITY CONTROL

### 3.1 Source QC

As every VP location had to be vibrated twice, there was some expectation on the ability to relocate the vibrating plate at the same position or even been able to vibrate a second time. A QC was made on the plate relocation accuracy (Figure 13).

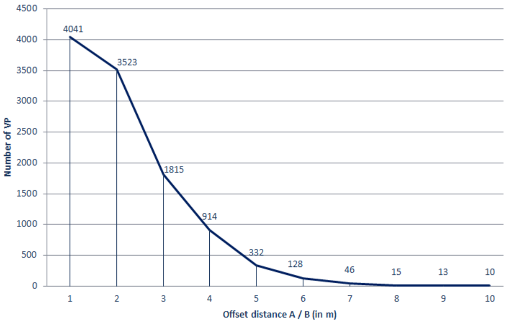

**Figure 13: Statistic of difference between the two different plate locations in WAS1 operations. (Source CGG)**

Finally, only 203 VsP over 17 151 were out of the 5m circle tolerance range around the theoretical vibration position.

The fold coverage was also finely controlled during acquisition to ensure that no extra short offset blind area could appear (Figure 14). Indeed, 3 low fold areas were identified due to access restriction, protected forest and wet areas.

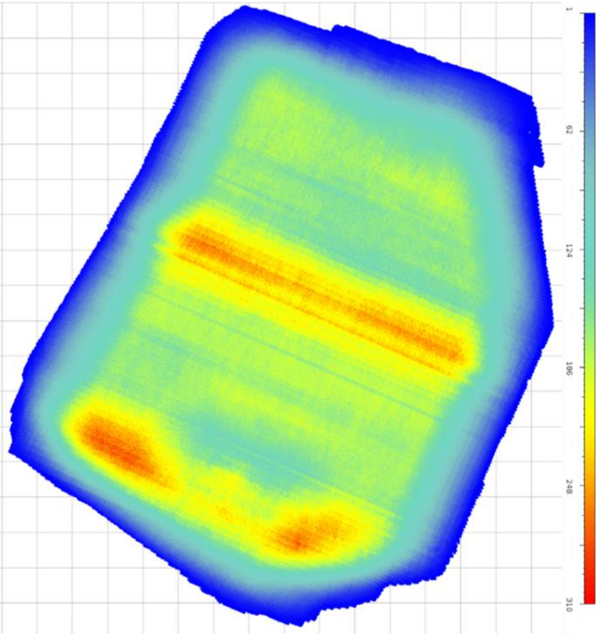

**Figure 14 : Fold map for offsets from 0 to 4400m (northern red strip is due to over coverage at WAS0-WAS1 transition – southern red strip is due to final merge of swathes during the last week of acquisition). (Source CGG)**

### 3.2 Receiver QC

Five crews equipped with tablet PC data harvester (Figure 15a) and one drone (Figure 15b) were dedicated to receiver QC. The objective was to check by rotation at least 90% of recording spread every 5 days.

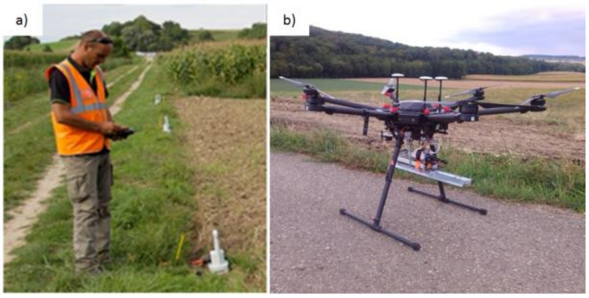

**Figure 15: a) Manual hand Data Harvester and b) RAU fast QC by drone. (Source CGG)**

On daily basis up to 1500 RAU or WTU-508 boxes where controlled.

At the central pathfinder all QC information’s brought by data harvester teams and the drone were centralized to validate the spread before giving the green light for vibroseis operations (Figure 16).

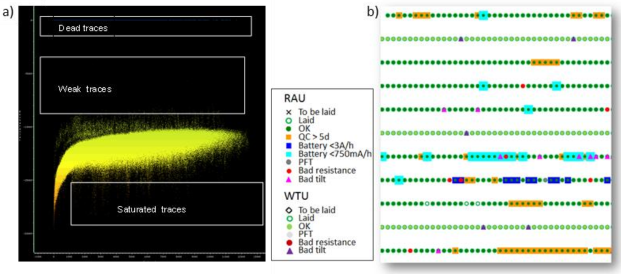

**Figure 16: a) Amplitude (Y) versus offset (X) QC attribute and b) view of QC database used for both RAU and WTU-508. (Source CGG)**

Furthermore a post-acquisition spatial QC was also performed to correct any unwanted movements experienced by the sensors. Indeed, each sensor was supposed to remain at a specific and invariant location for almost 12 days. Any displacements needed to be indicated in order to well reconstruct the final dataset (Figure 17).

**Figure 17 : Sensors (yellow circle) displacement (purple line) over the time. (Source CGG)**

### 3.3 On field PSTM QC

A comparison is made between the Teramig$^{TM}$ field cube (Cotton et *al., 2016*) and the preliminary PSTM processing results (Figure 18). Both processing flows differ in some points which leads to different images (noise level, dipping events, shallow/deep details). For easier comparison we applied a regional static difference to the preliminary Teramig$^{TM}$ cube in order to compensate the difference of replacement velocity used in the elevation statics (1800m/s for preliminary PSTM, 950m/s for Teramig$^{TM}$).

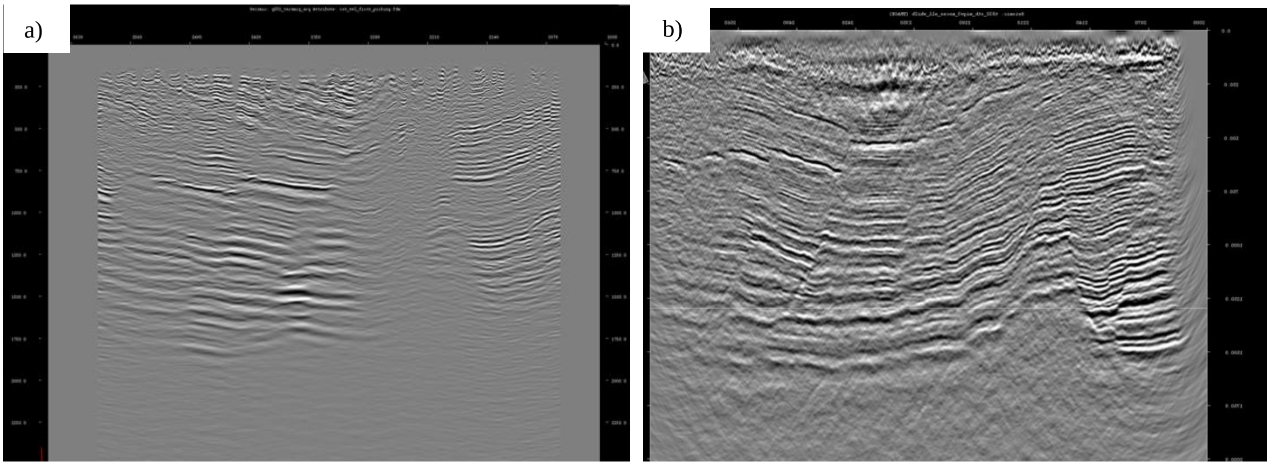

**Figure 18: IL11294 – a) Teramig$^{TM}$ volume and b) preliminary PSTM done at CGG processing center of Massy. (Source CGG)**

## 4. INDEMNITY FOR DAMAGE ON CULTURE

The implementation of project supervision under GIS (Geographic Information System) allowed developing a fully computerized procedure for compensation following damage to crops. Indeed, GPS tracking of vibratory trucks was collected and daily controlled. Among the 4,000 km travelled by vibratory trucks, about 500 km impacted crops (Figure 19).

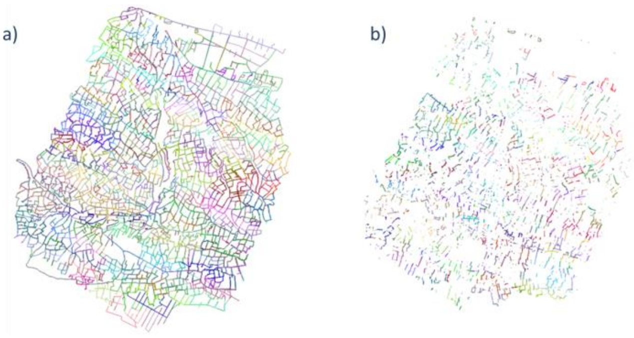

**Figure 19 : a) 4 000 km GPS tracks of all vibrotrucks (one color per day per vibrator) and b) residual way path in crops. (Source ESG)**

In agreement with the local Chamber of Agriculture, tariffs and widths of compensation were negotiated. Thus, a buffer of 4 meters was applied to the tracking of the vibrators and 1 meter for sensors deployment. The intersection between these buffers and the polygons of the agricultural parcels made it possible to calculate the impacted surfaces and to deduce the cost of compensation (Figure 20).

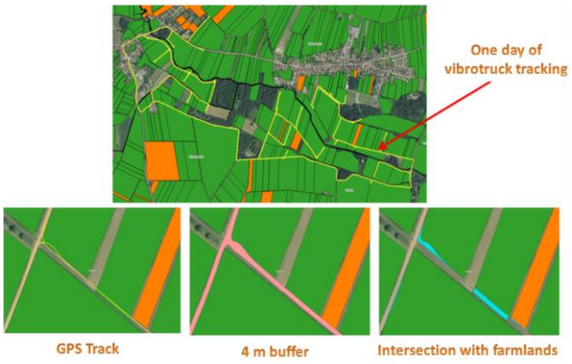

**Figure 20 : Illustration of the numerical methodology applied on vibrotrucks pass ways. Top image shows one day vibrotruck pass way in yellow. (Source ESG)**

A similar methodology was applied to calculate the impact of the deployment of nearly 23,000 sensors. Note that the satellite imagery highlights the good fidelity between the numerical methodology and the real impact on the field.

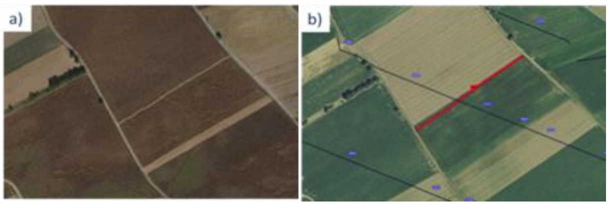

**Figure 21 : a) Satellite image of Northern Alsace at acquisition time. b) Numerical simulation of sensors deployment (in blue) and vibrotrucks pass way (in red). (Source ESG and Google Maps)**

### 5. PRELIMINARY RESULTS

At the time of writing this abstract, data processing (duration of 7 months) is underway. The creation of the static model as well as the first stages of denoising and velocity picking suggest excellent results and a much more well definition of geological structures.

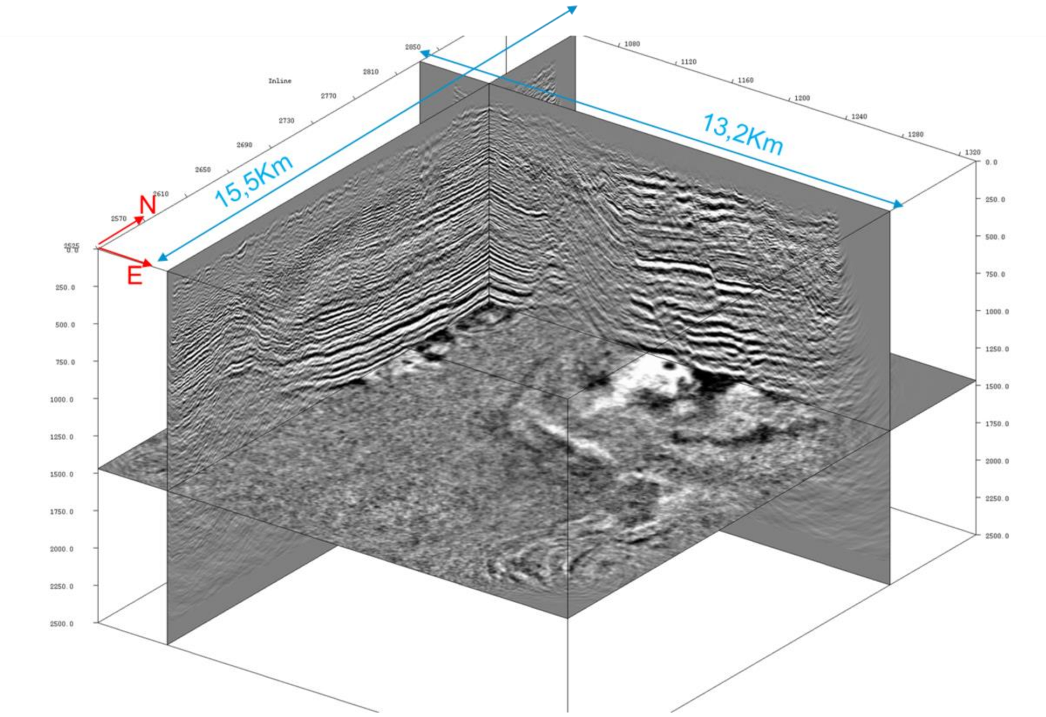

**Figure 22 : One inline, crossline and timeslice from the preliminary PSTM cube. Images obtained after application of the initial static model, 3D regularization and first pass of velocity analysis. Strong reflectors, major faults and the well-known horst of "Soultz-sous-Forêts" are already easily identifiable. (Source CGG)**

## 6. CONCLUSIONS

This first 3D seismic in the French Upper Rhine Graben was a success because of a strong acceptability, an effective permitting and a great reactivity of the teams to face the operational problems inherent to this kind of project. The first results, which are very promising with regard to the preliminary stage of treatments, also make possible to draw the conclusion that the acquisition parameters were appropriate for imaging the complex geological structures.

## REFERENCES

Cotton J., Beilles M., Mahrooqi S., Porter J., Denis M., Baris S., Forgues E. and Chauris H.: Automated and real-time field PSTM: How to QC more efficiently 10 billion traces today and more tomorrow, *78th EAGE Conference and Exhibition*, Expanded abstracts (2016).

Denis M., Brem V., Pradalie F., Moinet F., Retailleau M., Langlois J., B Bai, Taylor R., Chamberlain V., Frith I.: Can land broadband seismic be as good as marine broadband? – *The leading edge* – (2013) – pp. 1382-1388

Saleh A., El.Fiki A., Rodriguez J.M., Laroche S., Castor K.Y., Marin D., Bianchi T., Bertrand P., and Herrmann P.: A Step Change in Seismic Imaging Quality in Western Desert of Egypt - An Acquisition Case Study. *79th EAGE Conference and Exhibition*, Expanded abstracts (2017).

Sallas J., Gibson J., Maxwell P. and Lin F.: Pseudorandom sweeps for simultaneous sourcing and low frequency generation. *The Leading Edge*, (2011), 1162-1172.

## Acknowledgements

The authors would like to thank ES for sharing scientific results about an ongoing geothermal project. A part of this work was conducted in the framework of EGS Alsace research project, which is funded by ADEME “Agence de l’Environnement et de la Maitrise de l’Énergie”, a collaboration between industrial companies ES, ES-Géothermie, and Strasbourg University.

The authors also acknowledge the FEDER fund, “Fonds Européen de Développement Régional” for the financial support allocated to this 3D seismic project.

The authors would like to thank all the CGG-Land, Processing and Interpretation teams which were and still are fully focused on providing the more reliable data and results.

This work was partly performed in the framework of the H2020 DESTRESS EU project which has received funding from the EU framework programme for research and innovation under grant agreement No 691728.