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How to Upscale Geothermal Energy from Deep Fractured Basement in the Upper Rhine Graben? The Impact of a New 3D Seismic Dataset.

Alexandre RICHARD[1], Vincent MAURER[1], Hélène TOUBIANA[2], Xavier CARRIERE[2], Albert GENTER[1]

(1) ES-Géothermie, 5 rue de Lisbonne, 67300, Schiltigheim, France

(2) CGG - 27 avenue Carnot, 91300 Massy Cedex, France

alexandre.richard@es.fr

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ABSTRACT

During 2018 summer, a large wide azimuth 3D seismic reflection of 180 km² was conducted by Électricité de Strasbourg over the Northern Alsace region (France). The main objective of this first 3D seismic acquisition for geothermal project in France was to image the nearly-vertical fracture network of the Upper Rhine Graben, to be able to design a multi doublet EGS geothermal project and to reduce drilling risk by optimizing the borehole trajectory by taking into account the geometry of the natural fracture/fault system.

In order to achieve optimized well trajectories within the complex nearly vertical fractured area of Northern Alsace, a one year of data processing and interpretation was needed. This detailed investigation of 3D seismic data lead to a high resolution 3D cube of seismic data converted in depth. These data have benefited of a broadband acquisition and state of the art of seismic processing workflow. It results unrevealed geological faults probably making of Northern Alsace, the French most promising high temperature geothermal reservoir. Indeed, the development potential of Northern Alsace was confirmed by a recent hydraulic interference test between the Soultz-sous-Forêts wells and Rittershoffen geothermal sites far from seven kilometers showing however their hydraulic connection.

This paper will describe the cost effective acquisition parameters selected to properly image the deep geothermal target corresponding to deep-seated fractured rocks, the processing workflow followed and the most relevant geophysical attributes produced to figure out high potential geothermal targets.

1. INTRODUCTION

As the company 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 deep geothermal fractured reservoir. In this area, the geothermal resource is mainly located in the crystalline basement which is highly fractured and hydrothermally altered (Vidal et Genter, 2018). Thus, this 3D seismic survey was designed for imaging the root of the fault system, characterized by normal faults, cross-cutting the bottom of the sedimentary basin (Permo-Triassic sandstone) or the top basement (Paleozoic granite).

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

In particular, broadband seismic (Denis et al. 2013, Sallas et al. 2011) 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 (Cordsen et al. 2002, Meunier et al. 2008) might be major breakthroughs in order to reach the geothermal target, constituted by permeable faults crossing both sedimentary layers and crystalline basement.
In order to achieve optimized well trajectories within the complex nearly vertical fractured area of Northern Alsace, a one year of data processing and interpretation was needed. This detailed investigation of 3D seismic data lead to a high resolution 3D cube of seismic data converted in depth. These data have benefited of a broadband acquisition and state of the art of seismic processing workflow. It results unrevealed geological faults probably making of Northern Alsace, the French most promising high temperature geothermal reservoir. Indeed, the development potential of Northern Alsace was confirmed by a recent hydraulic interference test between the Soultz-sous-Forêts wells and Rittershoffen geothermal sites far from seven kilometers showing however their hydraulic connection.
This paper will describe the full management of the 3D seismic acquisition, the processing workflow, the final PSDM results and preliminary designed targets thanks to all of these data.

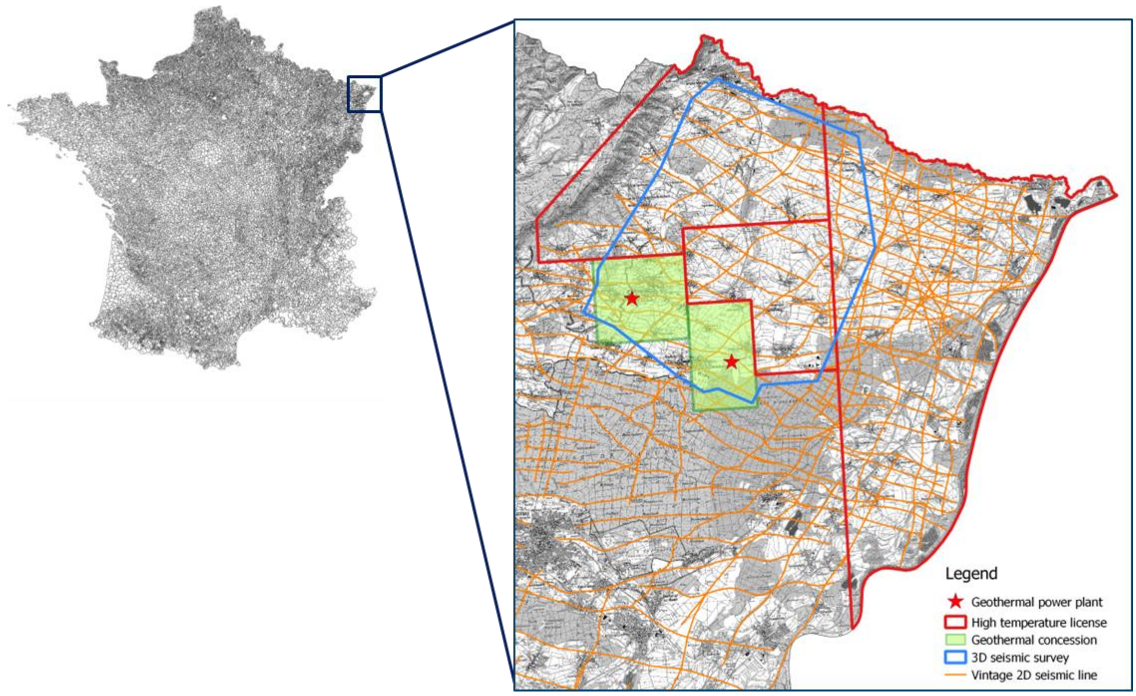

Figure 1: Regulatory and geophysical context of the 3D seismic exploration survey in Northern Alsace. (Source ESG)

2. SEISMIC ACQUISITION: BEHIND THE SCENE OF A SUCCESS

2.1 CONTEXT

The most visible upscaling is the evolution of the exploration strategy in the French URG. Indeed, the Soultz-sous-Forêts HDR project was carried out without additional seismic exploration. The Rittershoffen EGS project was carried out on the basis of two 2D seismic lines. These explorations of small scale did not allow considering several projects on the same license nor even more than one doublet power plants. Indeed, designing a four wells EGS project need a consistent knowledge of faults structure.

The recent interference test between the wells of the Soultz-sous-Forêts power plant and the Rittershoffen thermal plant highlighted the connectivity of the reservoir between these two sites, several kilometers apart (Figure 2).

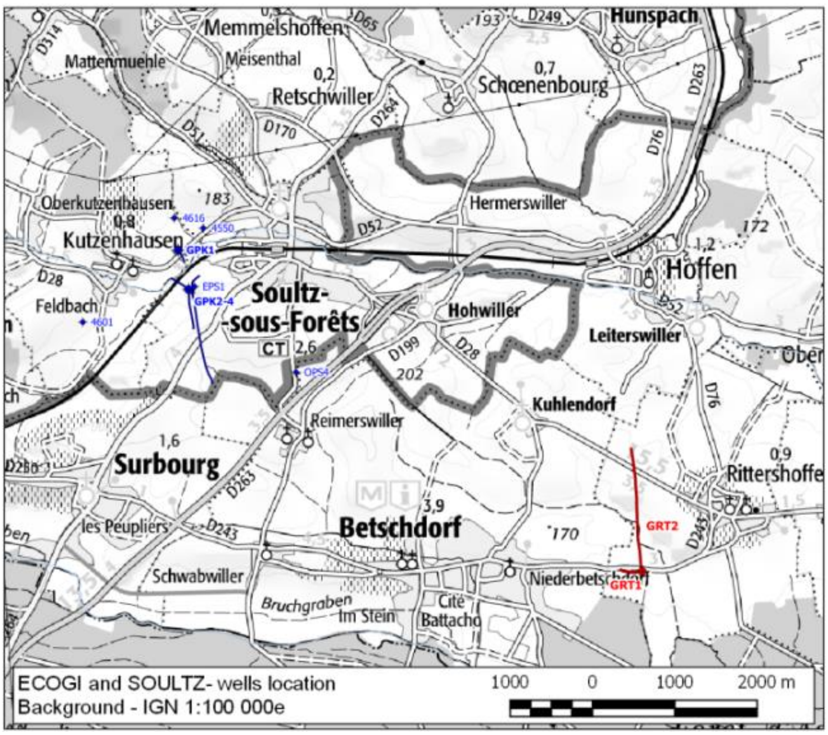

Figure 2: In blue the instrumented wells of Soultz-sous-Forêts with high sensitive pressure sensors. In red are shown Rittershoffen well heads and trajectories. (Source ESG)

The result of this test was one of the arguments put forward to validate the large-scale design (second largest acquisition in metropolitan France) of 3D seismic acquired in summer 2018. The definitive survey was defined by the conjunction of geophysical (offset, wide azimuth), hydrogeological (conceptual circulation model from Schellschmidt et al. 1996, Pribnow et al. 2000, Vidal et al. 2018), structural (faults identified on vintage seismic), surface (protected area) and financial constraints (Figure 3).

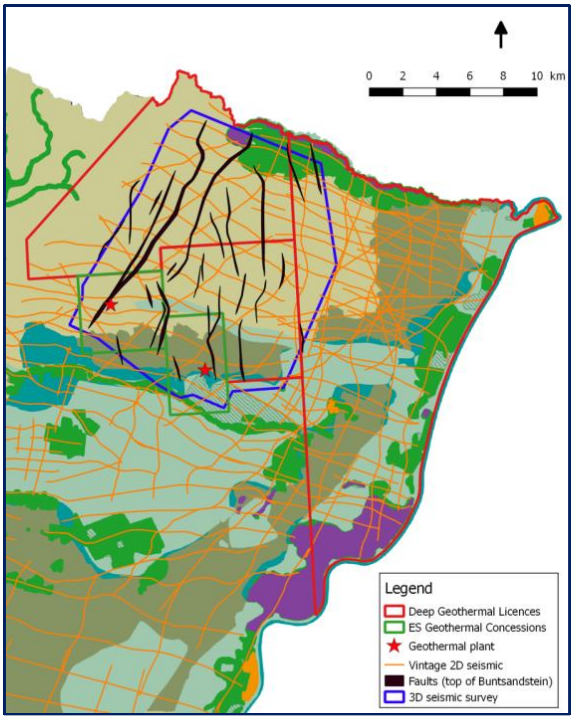

Figure 3: Map of all parameters taken into account to define the final 3D seismic survey. (Source ESG)

The different licenses were respectively covered at 80%, 98% and 10% by the 3D seismic. Furthermore, the exploration reached both active power and thermal plants (red stars in Figure 3) in ordered to benefit of all well data (sonic, check-shot, lithology, logging…). Indeed, Toubiana et al. 2020, highlighted the importance of calibrating seismic data to wells, in terms of velocity and well tops.

2.2 ACQUISITION PARAMETERS

In order to determine the appropriate parameters for geothermal target imagery (basement / sediment interface), an in-depth analysis of vintage seismic was performed. Mainly dedicated to the imaging of shallow oil layers (Pechelbronn layer), the acquisition parameters and in particular the sweeps were therefore poorly suited to geothermal targets (Figure 15). The high frequency sweep (up to 140 Hz) had few penetrations. Final confirmation was possible through a test day (Charles et al. 2016) in the seismic 3D area where several ranges of sweep were tested. The following figure (Figure 4) clearly shows that no frequencies above 96 Hz were reflected.

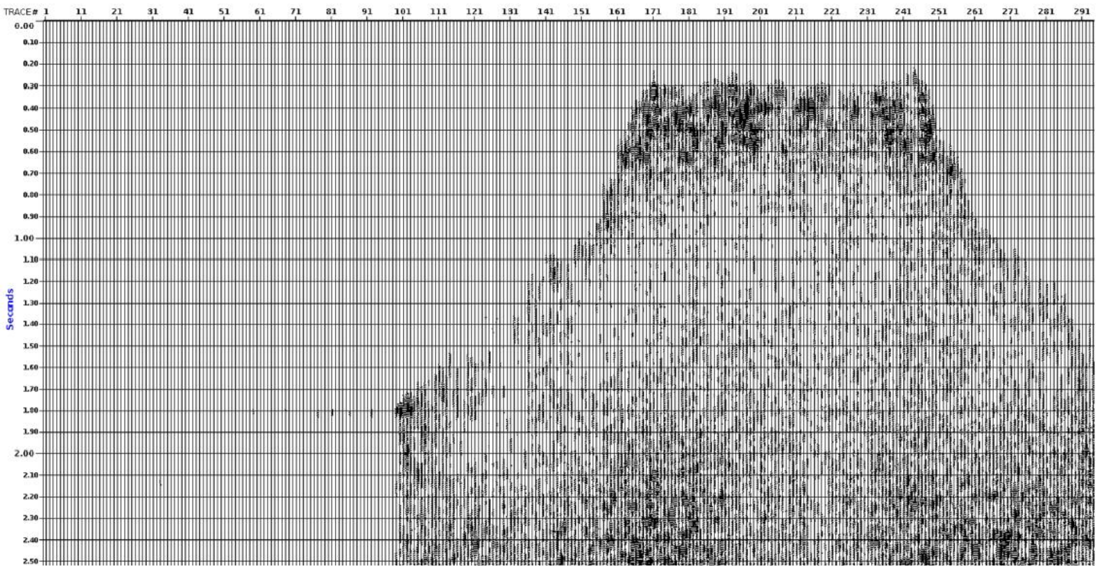

Figure 4: 2D seismic line acquired to validate the sweep parameters. This section was acquired with a SRS sweep of [2 - 130] Hz and then filtered with a high pass filter ([96 - 110] Hz). (Source CGG)

The distance between receiver lines, as well as the distance between source lines (Table 1) were mainly constrained by the feasibility of these parameters with regard to the surface constraints (density of roads, villages, fields…).

The distance between traces, as well as between vibrated points (Table 1) were determined by the size of the desired bin and the budget aspect. The inter-trace should have been determined from the wavelength of the surface noises and in particular the ground-roll. However, the latter propagated at a very low speed (250 m / s) theoretically imposing an inter-trace of 2.5m (Toubiana et al., 2020), economically and technically impossible to respect.

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

Finally, these parameters lead to a wide azimuth geometry up to 3 000m and a nominal 3D fold of 150 (Figure 5).

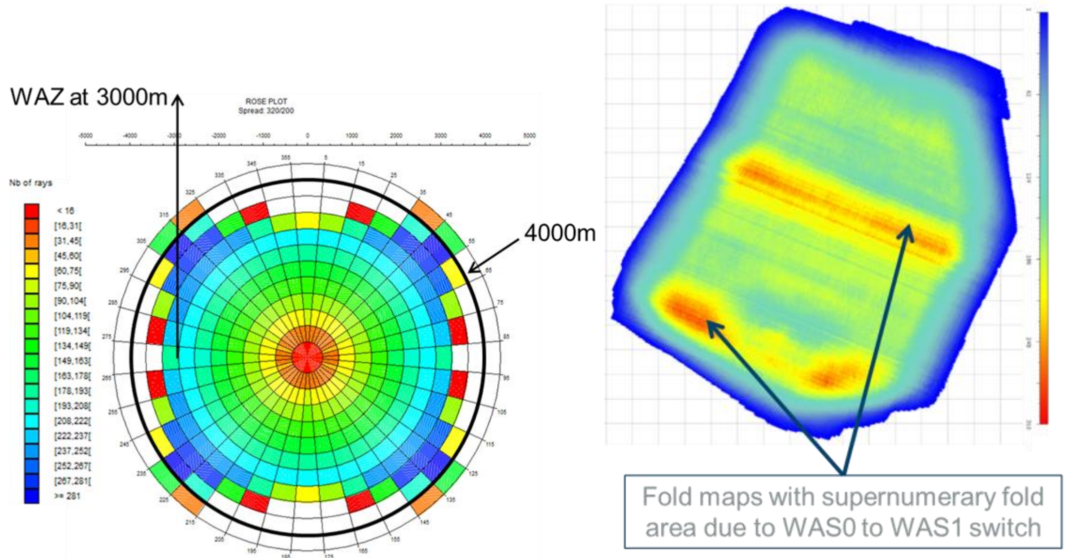

Figure 5: Rose diagram showing the wide azimuth geometry up to 3 000m (left) and the fold map (right). Supernumerary fold is explained in §2.3. (Source CGG / ESG)

As detailed in Figure 4, the high frequencies could be limited to 96 Hz in the case of this 3D seismic. Concerning the low frequency and without prior information of granite seismic response, it was decided to use the lowest possible frequency. CGG was able to provide such a low frequency (sweep starting at 2 Hz) with high quality control (Table 2).

Table 2: Technical description of deployed equipment.

Sweep	[2-96] Hz	Single 48s SRS / Emphaseis sweep per 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

Figure 6: Seismic equipment deployed. From left to right RAU (digitizer, 20 000 deployed), WTU (digitizer, 3 000 deployed) and SG10 (string of 6 geophones). (Source Sercel)

As 6 000 vibrated points were located closer than 10 m of a building, the pseudo-random sweep combining low impact on building and high productivity rate was definitively the one needed in this case (Meunier et al. 2008, Sallas et al., 2010).

Concerning equipment deployed at the ground, a mix of RAU and WTU (Table 2 and Figure 6) was selected to reach both high density of sensor and effective field QC provided by the WTU (Table 2). Using such wireless system make the acquisition mainly blind in terms of data QC. So one line of WTU was deployed each four lines of RAU to benefit from the WTU real-time QC (Figure 7).

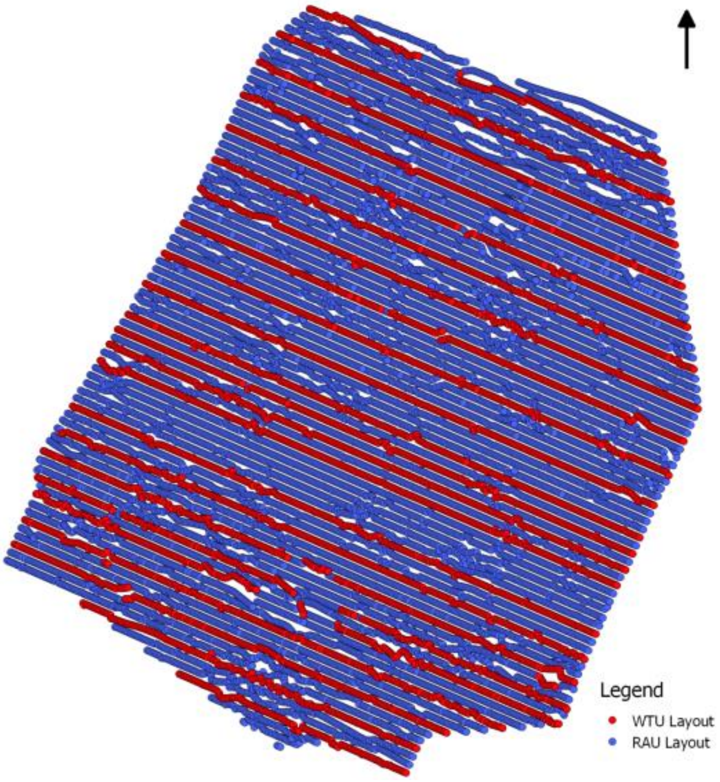

Figure 7: RAU and WTU deployment strategy to provide high receiver density and quality control. (Source ESG)

For the source effort, 30 tons vibrotrucks delivering 276 kN were selected (Figure 8). Thanks to the SRS technology up to 10 vibrotrucks were shooting at the same time. The contractual high drive and low drive were respectively 80% and 40%.

Figure 8: Mertz 26HD-623B (deployed number: 9) - Peak force output 276 kN (62 000 lb). One AHV- Peak force output 275 kN (62 000 lb) with soundproofing system was also deployed but mainly in cities. (Source ESG)

2.3 FIELD OPERATIONS

2.3.1 PERMITTING

Before deploying all this equipment in the field, an intense permitting job was necessary including meeting with mayors (42), citizens (3 public conferences), hunters and farmers to finally obtain the following access map within the whole 3D area (Figure 9).

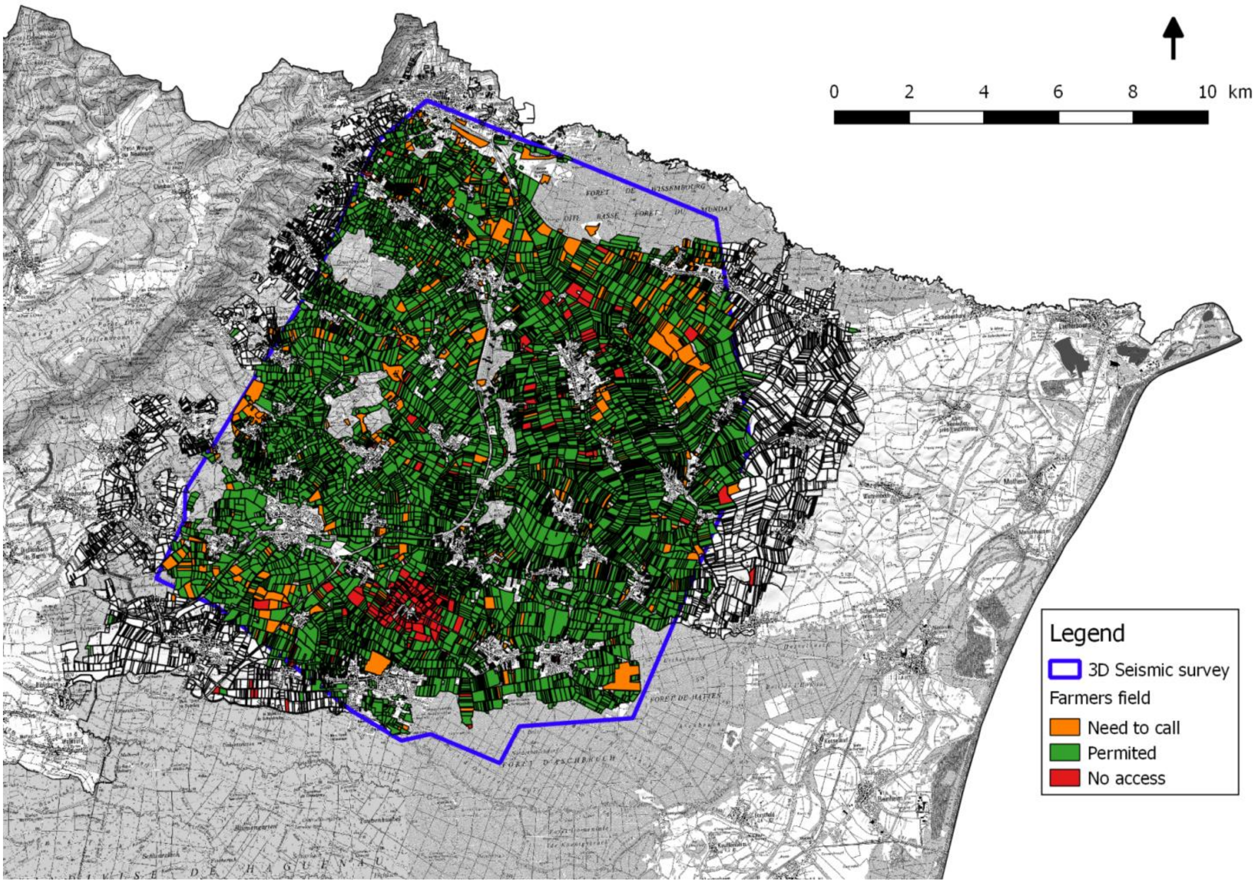

Figure 9: Map of farm lands (13 000) within the 3D seismic survey (blue polygon). Authorized accesses are shown in green, refused or not crossable in red and orange parcels need prior contact. (Source ESG)

This map is actually the first success in terms of upscaling because it needed a large acceptance of the project in the northern Alsace.

2.3.2 "CORN MARE"

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).

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 RAU / WTU and geophone strings already laid 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 deal 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 were 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).

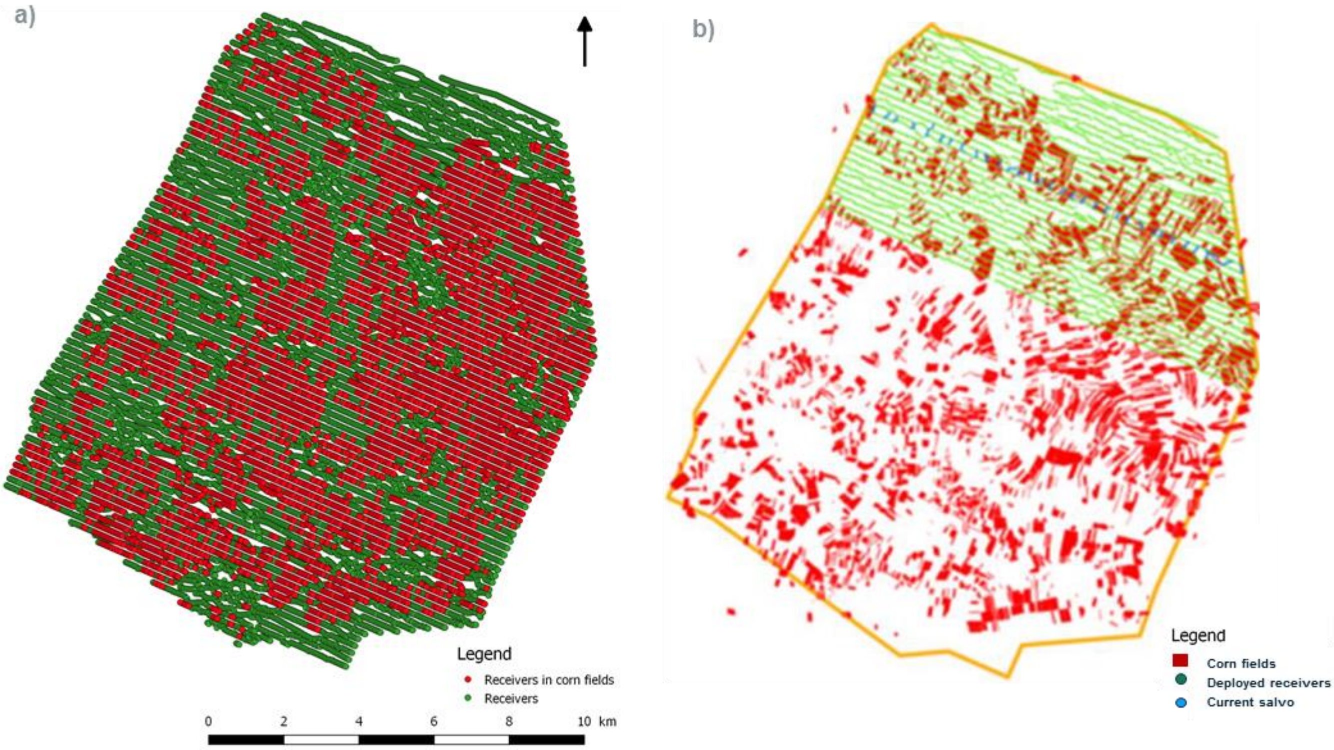

Figure 10: a) Receiver position with in red receivers located in corn fields (Source ESG) and b) location of corn fields (red polygons) and deployed receivers at the end of August (green dots). (Source CGG)

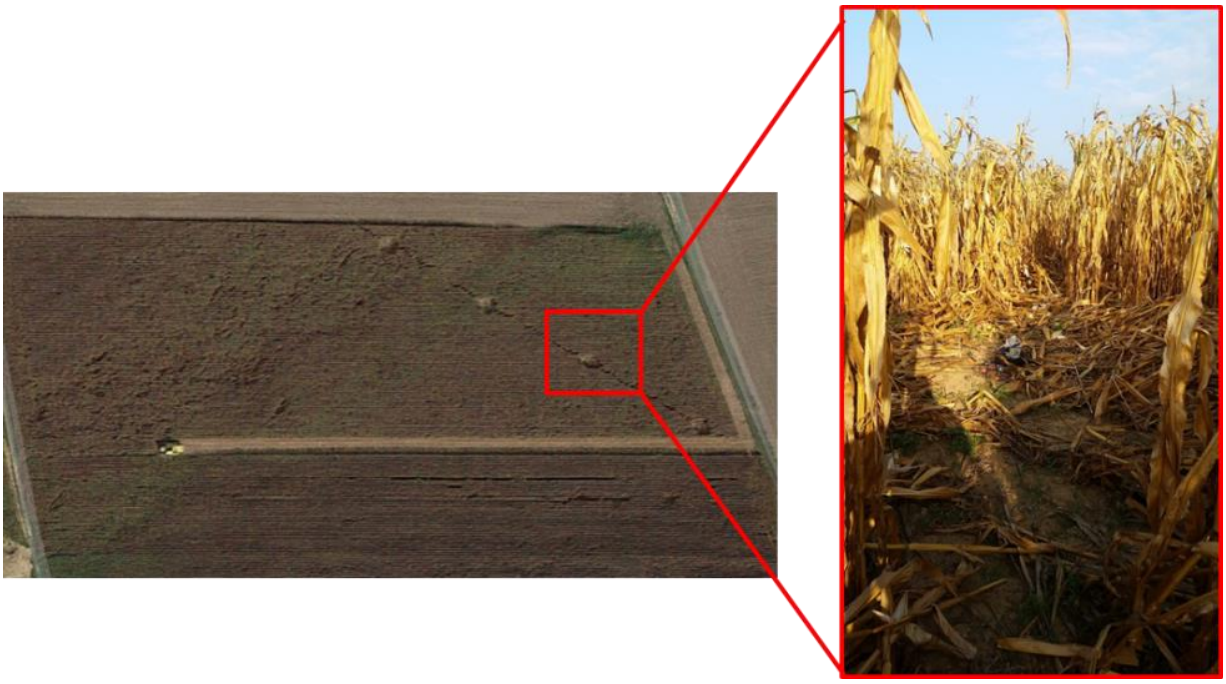

Figure 11: left image shows a combine starting to harvest the corn field (Source Google Maps) and the zoom (right image) focus on a bunched trace with "protection area" of crushed corn. (Source ESG)

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).

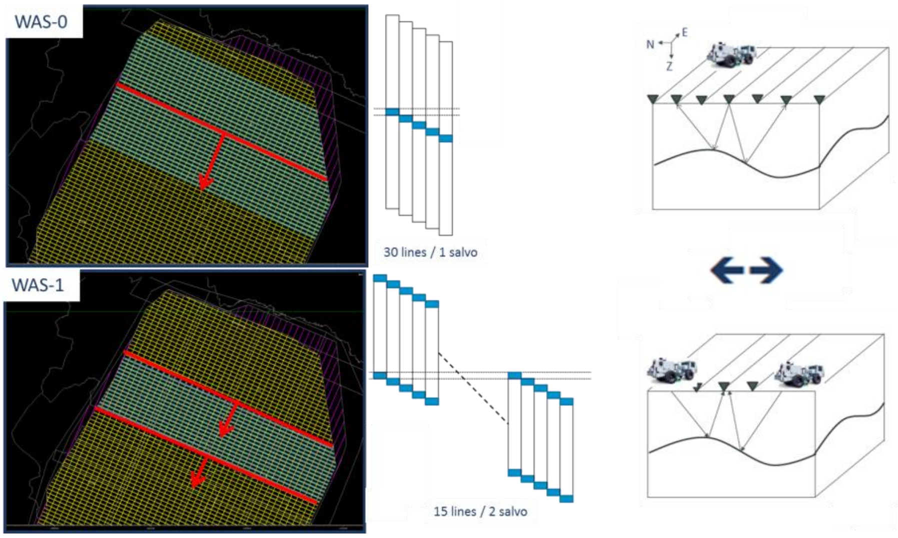

Figure 12: Transition from 30 WAS0 active lines (top) and a 15 active lines WAS1 swath (bottom). (Source CGG / ESG)

2.3.3 COMPENSATION

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 13).

In agreement with the local Chamber of Agriculture of Alsace, 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 13).

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 13).

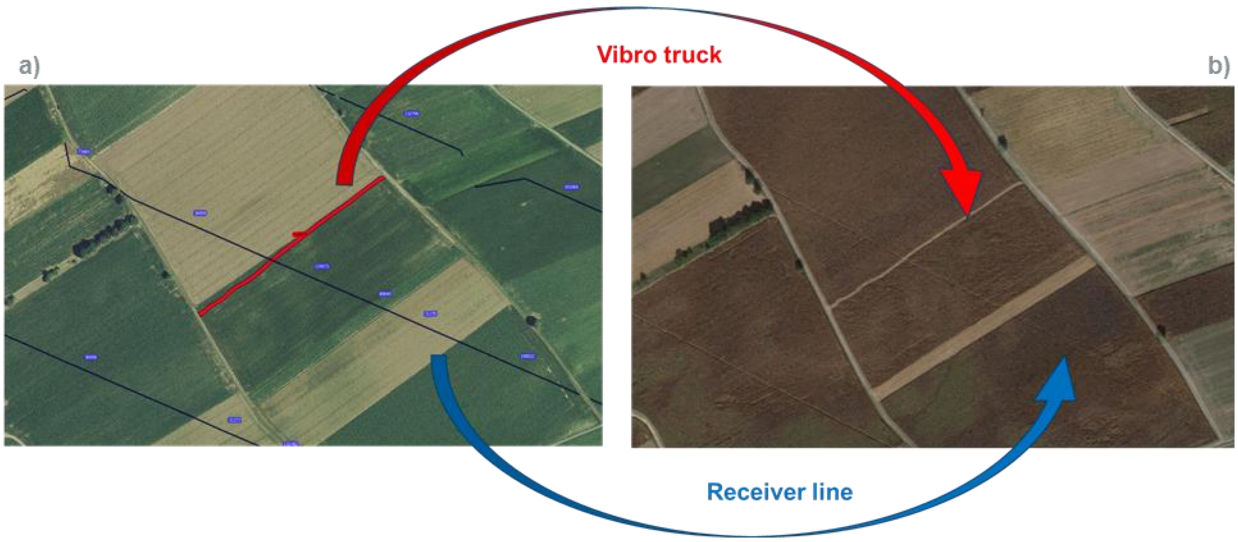

Figure 13: a) Numerical simulation of sensors deployment (in blue) and vibrotrucks pass way (in red). b) Satellite image of Northern Alsace at acquisition time. So the digital compensation procedure was relevant and finally well accepted by farmers. (Source ESG and Google Maps)

3. RESULTS

3.1 METHODOLOGY

After a challenging seismic acquisition, a 9 month processing time started. CGG has implemented a testing and validation procedure routinely going to a QC on Pre-Stack Time Migration, PSTM (Figure 14). This method, which is costly in both man and machine, has proved to be a major asset for data processing.

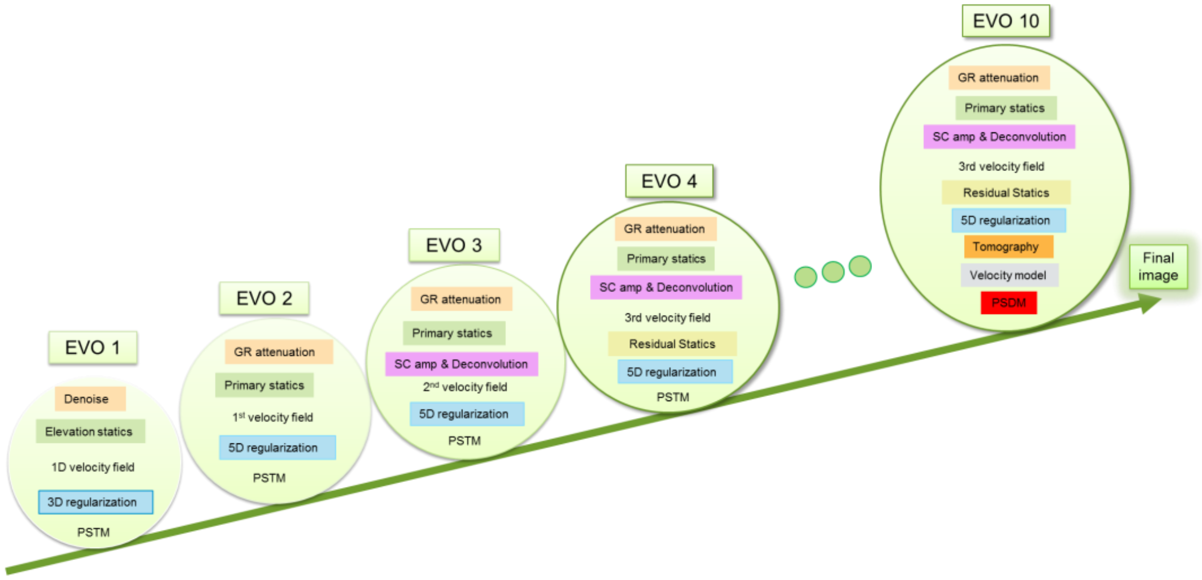

Figure 14: The iterative QC procedure implemented by CGG. Each major step was validated by a PSTM cube. (Source CGG / ESG)

As we are dealing with a complex faulted structure combined with pull-apart basins, horsts, synthetic / antithetic faults, mainly oriented N20° but also N170° and to fully benefit of the wide azimuth acquisition, the processing sequence goal was to achieved a Pre-Stack Depth Migration, PSDM cube (Figure 17).

3.2 VINTAGE 2D VERSUS NEW 3D SEISMIC

To analyze the success of this acquisition, a comparison of the newly acquired data and the vintage 2D seismic can be performed (Figure 15).

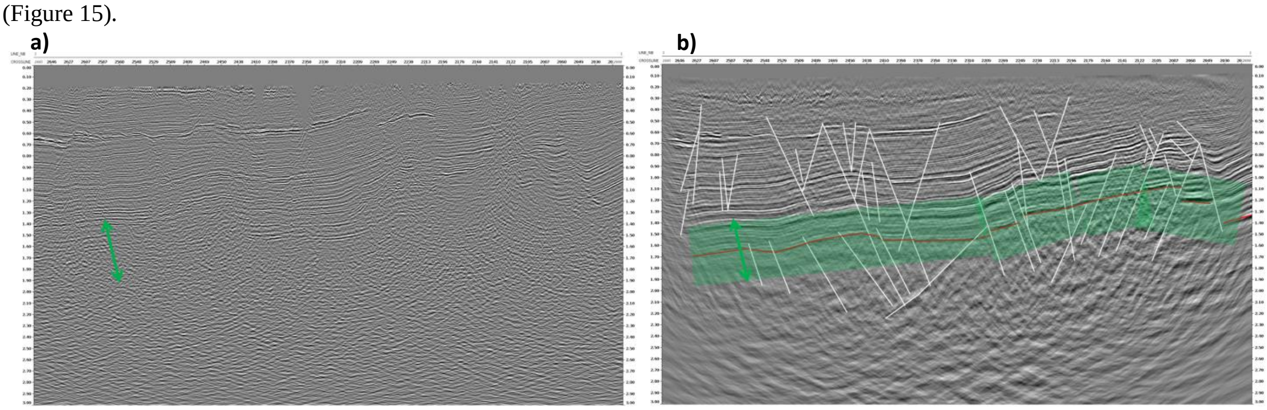

Figure 15: a) 2D vintage PSTM of 1984 and b) 3D seismic PSTM of 2018. White lines are faults, green area is the newly visible seismic layers and the red line is the top of the granite. (Source ESG)

On the vintage data, the last horizon that can be continuously picked was the Muschelkalk. On the newly acquired seismic, the top of the granite can easily be picked on the whole 3D cube. So a gain of 600 ms was achieved combining state of the art acquisition and processing. Furthermore, faults affecting granite are now clearly identifiable (white lines in Figure 15).

Right now the interpretation process is still ongoing but preliminary results (Figure 16) are very encouraging and suggest that it will be possible to design multi-well projects with multiple faults crossing the granite as target.

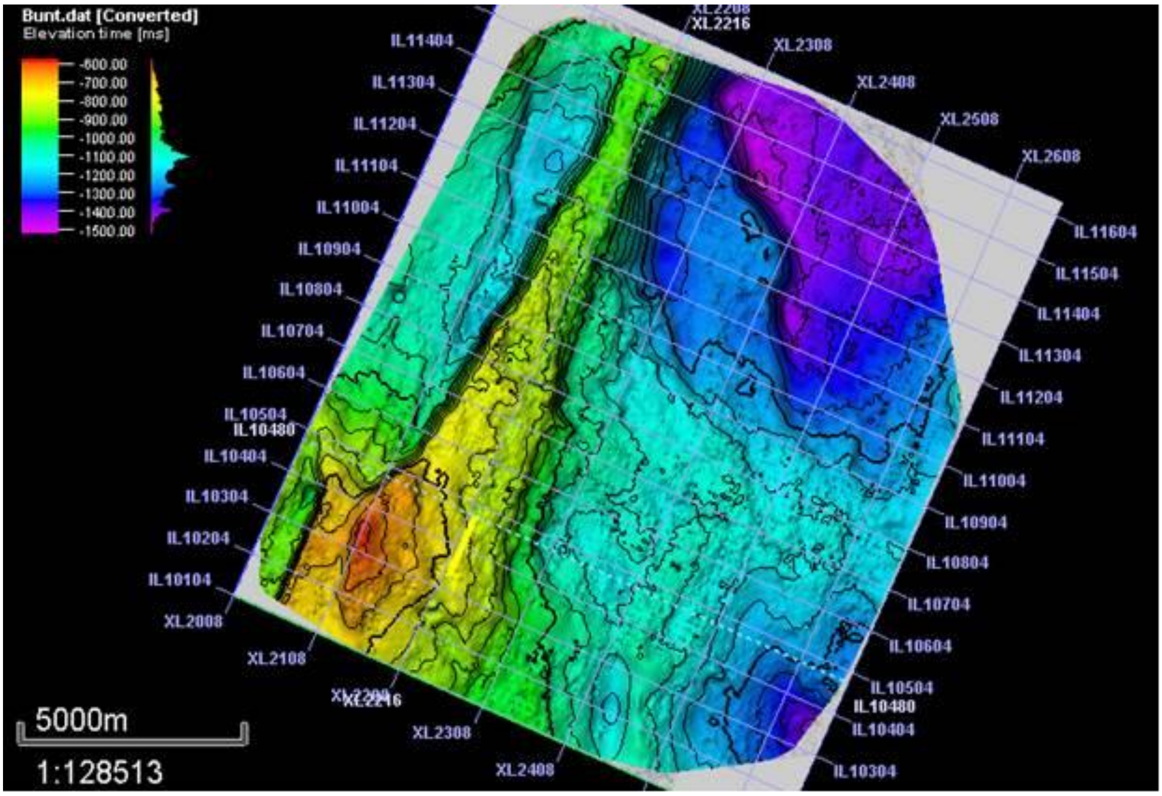

Figure 16: Map of the top of Buntsandstein layer. The well-known "Horst of Soultz-sous-Forêts" is clearly identifiable as well as N170° major faults. (Source ESG)

3.3 BENEFICE OF PSDM

As explained in §3.1.1, the goal of the advanced processing workflow used in this study was to obtain a PSDM cube in depth. The Kirchoff Pre-Stack Depth Migration is well known to focus and position reflections in areas with strong lateral velocity variations (Charron et al., 2011) with is the case for aborted rifting structure like the Upper Rhine Graben.

On Figure 17, two faults affecting the granite are underlined on the PSDM section. However on the PSTM, the first fault was not visible when the second one was positioned 320 m too far east. Such a positioning error could be dramatic for an EGS geothermal project.

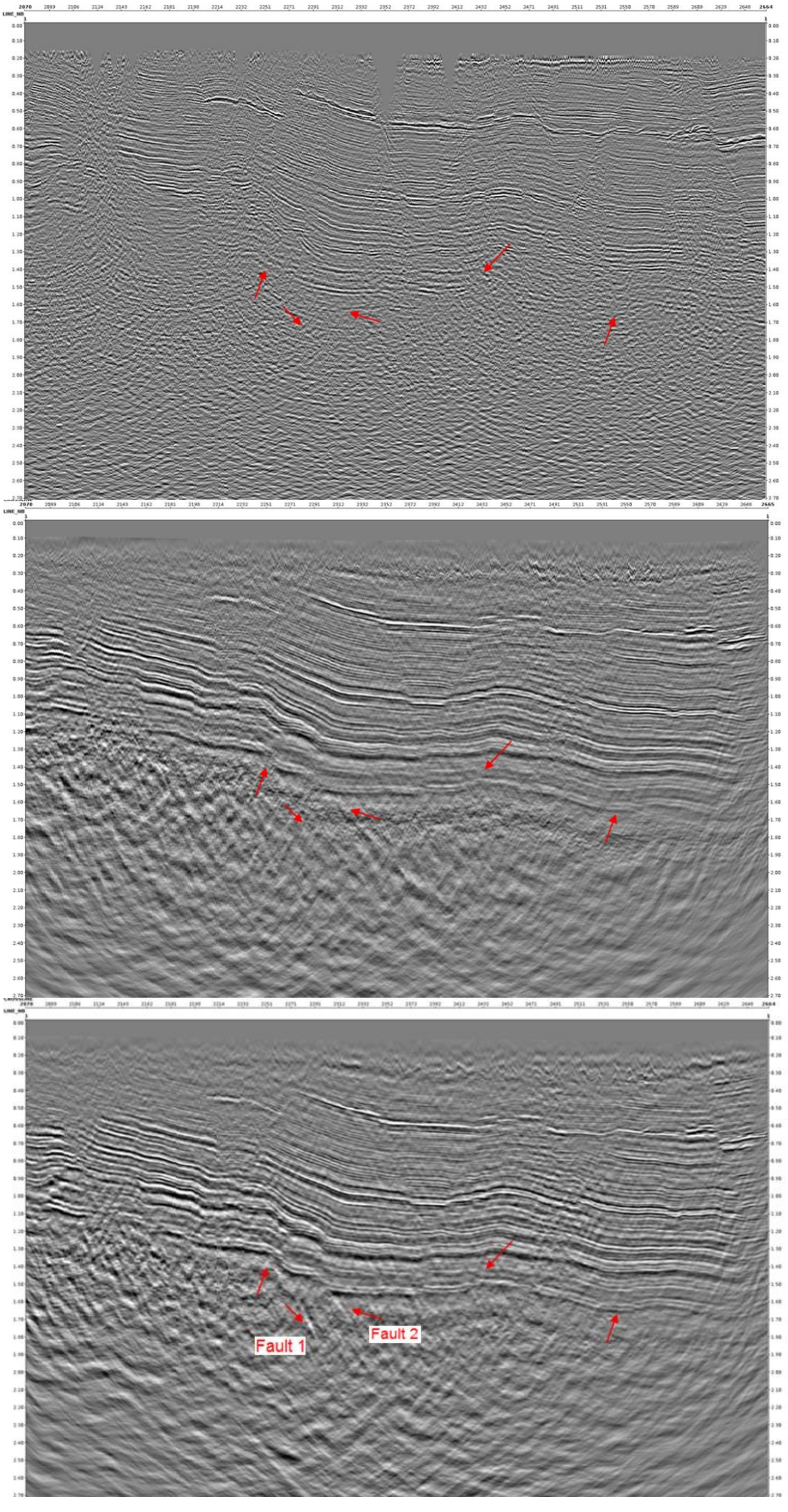

Figure 17: Top figure is a 2D vintage PSTM, middle is a 2018 3D inline PSTM extracted from the cube and the figure at the bottom is a PSDM in time of the same inline. (Source CGG)

The 3D PSDM cube in depth will be used to design multi-wells EGS project (Figure 18) by targeting several faults from the same platform to drastically reduce cost of a geothermal project.

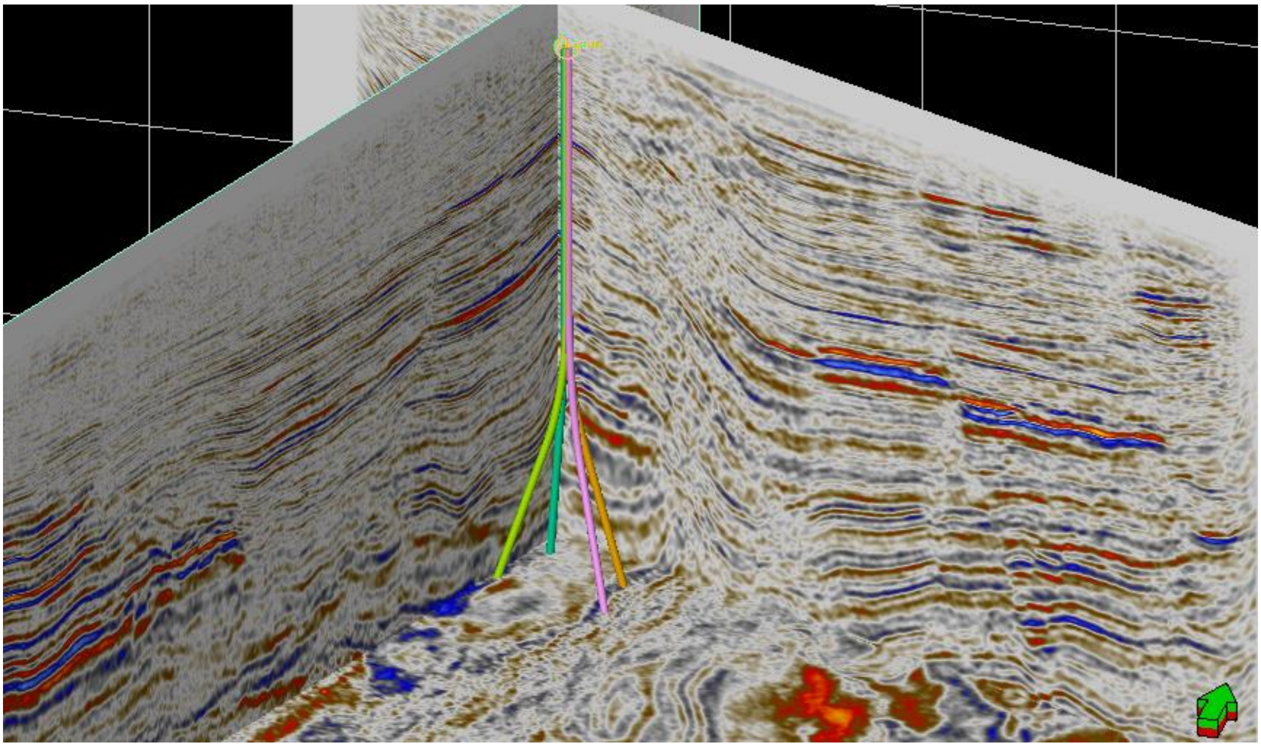

Figure 18: Preliminary well trajectories for the next EGS project in the northern Alsace. Arrow indicates North direction. (Source ESG)

4. CONCLUSION AND PERSPECTIVE

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. Thanks to the processing workflow providing as final deliverable a PSDM cube in depth ESG will be able to design multi-well projects.

The ongoing interpretation process will also provide decision tools with all the seismic layers and faults finally picked. 3D attributes as coherency map and advanced fault mapping (AFE, Automated Fault Extraction) will also provide useful information to position future geothermal wells.

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REFERENCES

Charles S., Leslie A., Cotra M., Winter O., Lin F., Caille C., Testing, Testing –A case study of a successful seismic acquisition startup test programin the oilsands. *GeoConvention 2016.*

Charron P., Ravaut P., Riou A., Sirgue J., Zuwaimi M. N.: Benefits of PSTM and PSDM Reprocessing in the Exploration of the Deep Malay Basin. *International Petroleum Technology Conference, 15-17 November, Bangkok, Thailand 2011.*

Cordsen A., Galbraith M.: Narrow- versus wide-azimuth land 3D seismic surveys. *The Leading Edge (2002), 21(8), 764–770.*

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.*

Meunier J., Bianchi T., Postel J-J., Taylor R.: The future of vibroseis for high-density wide-azimuth land acquisition. *First Break volume 26, February 2008.*

Pribnow, D., & Clauser, C., (2000). Heat and fluid flow at the Soultz Hot Dry Rock system in the Rhine Graben. *Proceedings of World Geothermal Congress 2000. Kyushu - Tohoku, Japan.*

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

Schellschmidt, R., & Clauser, C., (1996). The thermal regime of the Upper Rhine Graben and the anomaly at Soultz. Zeitschrift für *Angewandte Geologie 42, 40–44.*

Toubiana H., Salaun N., Mitschler J-B., Gigou G., Carriere X., Richard A., Maurer V.: Designed 3D Seismic Imaging to Better Understand Geothermal Faulted Reservoir, an Upper Rhine Graben Case History. *Proceedings of World Geothermal Congress 2020.*

Vidal, J., & Genter, A. (2018). Overview of naturally permeable fractured reservoirs in the central and southern Upper Rhine Graben. *Insights from geothermal wells. Geothermics, 74, 57-73.*