# *Towards targeting geothermal reservoir: guide from survey design to processing through seismic acquisition in urban context in Alsace*

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## Introduction

Based on the geothermal expertise gathered from the Soultz project which was successfully demonstrated with the recent geothermal doublet of Rittershoffen, new targets in the Upper Rhine Valley are under development by the Groupe ES (Genter et al., 2015a). Thus, as part of a geothermal project in Alsace (France), a preliminary survey of seismic reflection was acquired during summer 2015 at Illkirch in the suburb of Strasbourg area. The deep geothermal target is a fractured/faulted zone at the interface between the deep clastic sediments and the top crystalline basement. This seismic survey was designed in order to qualify a potential deep geothermal target for an EGS (« Enhanced Geothermal Systems ») exploitation of the resource (Genter et al., 2015b).

Obtaining a structural and hydrogeological model of this kind of deep fractured reservoir is a key point for a successful project (Dezayes et al., 2010). So geometry design and acquisition parameters have been discussed to provide a suitable and valuable image of the sub-surface. Furthermore within a complex structural model, a seismic processing sequence dedicated to enhance fault direction should be implemented.

Beyond technical considerations, being environmentally concerned and scientifically transparent the “Groupe ES” is willing to develop local energy for local purpose to ensure the acceptability by people to the project.

## Design of seismic lines for a cost effective acquisition

First of all, the strategy in place is to reprocess old seismic lines in the vicinity of the interest zone to obtain first order information at a quite low cost. Then, the design of the next seismic acquisition was more focused on a specific area, mainly to ensure that trajectories of the wells are crossing the target. In the case of the Illkirch-Graffenstaden project in Alsace, exploration area was reduced to approximatively 30km². Acquiring 37km of 2D seismic lines was sufficient to obtain enough information to characterize the targeted fault without any exploration drilling (Figure 1).

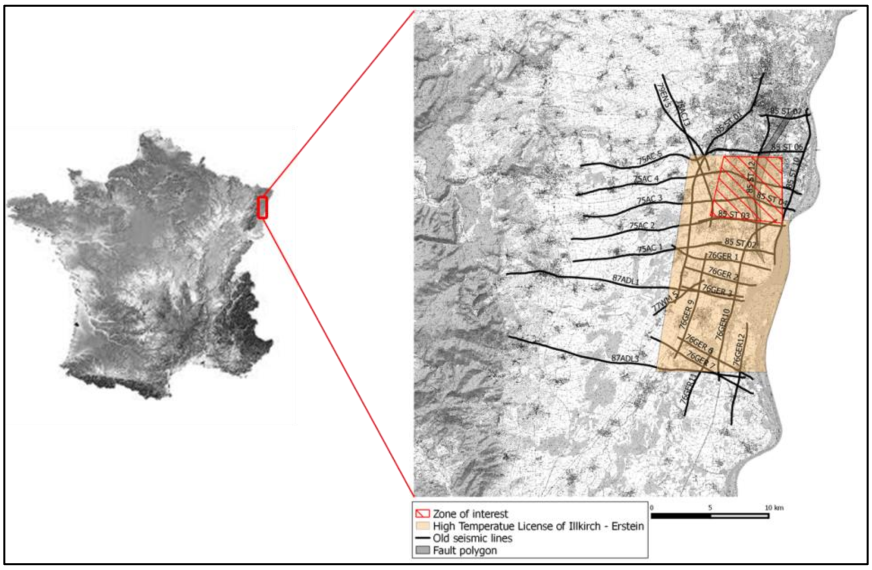


*Figure 1 : Refining the zone of interest within the high temperature license*

However in order to take maximum advantage of the information coming from the previous seismic acquisition, the new survey design had to take into account the previous geometry of the lines and the previous parameters used to acquired data respectively in 1975, 1977 and in 1985. In order to densify the spatial coverage, to increase the seismic resolution and to keep a coherent global design the decision was taken to add three East-West lines (Figure 2). As a consequence, the distance between lines of the 1985's acquisition was reduced by half.

To correctly image faults with a significant apparent dip, seismic lines have to be as perpendicular as possible to the fault plane direction (Lavergne et al., 1986). But due to the large distances between old seismic lines, an important uncertainty was remaining on fault geometry. So to have a better azimuthal constrains and also to have information all along the wells trajectories, two extra-lines respectively NW-SE and NW-SE were designed.

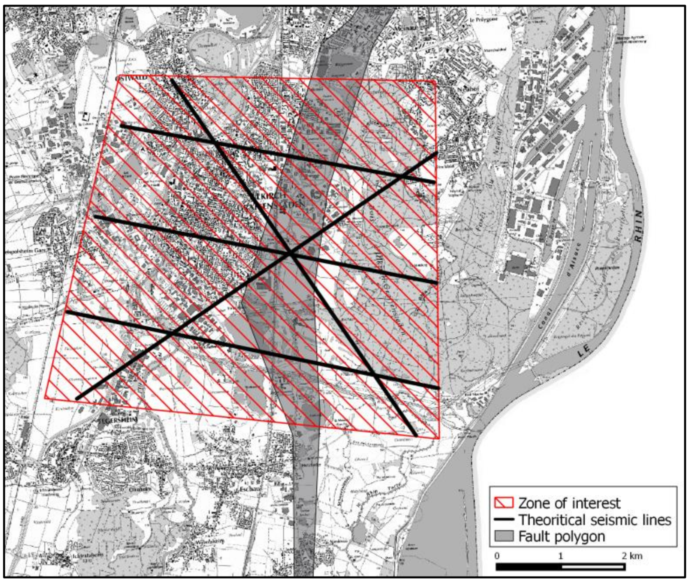


*Figure 2 : Final theoretical survey design for the newly acquired seismic reflection*

The obliqueness of these lines compared to the main fault plane direction remains low enough to ensure a right migration of the sloping reflectors (Yilmaz et al., 1987, 2010) while allowing intersection of possible faults in between two seismic lines.

## Acquisition parameters and seismic processing sequence

Ideally, accurate information about the target depth, the frequency content and propagation velocities in the different geological layers are necessary to define the key parameters of the seismic acquisition. Thereby, the contribution of reprocessing and reinterpretation of old seismic lines provide access to the necessary information to define the optimal geometry that will properly image the deepest layers down to the top basement and the identified target.

From a cost point of view, in seismic acquisition and later its processing and interpretation, it is the total line legnth which is the overriding factor (Bouska et al., 1997). Therefore, it is necessary to precisely determine the extent of seismic recording device. As a first approximation the extension of the network, otherwise known as "offset", is commonly taken equal to the depth of the target. However, this first order estimate may be largely wrong if the seismic wave propagation velocities are not taken into account. So, for a more rigorous estimate of maximum offset, this formula should be used (Talagapu et al., 2005).

$$Offset_{max} = \frac{Z}{2}\left(\frac{V + V_s}{V - V_s}\right)^{\frac{1}{2}} \times \tan\theta$$

$Z$: target depth
$V$: average velocity of the target layer
$V_s$: velocity of the surface layer
$\theta$: maximum dip of the target horizon

*Equation 1 : Maximum offset estimation in function of velocities, target depth and maximum dip*

Lack of offset could dramatically affect the data and even worse when it comes to image a fault scarp. As shown on figure 3, shortened offset could not clearly reveal reflectors of the foot wall. That would result in a complex tracking of laterally consistent seismic reflectors and finally to an inaccurate interpretation of the layer depth and of the position of the targeted fault (Ourabah et al., 2014).

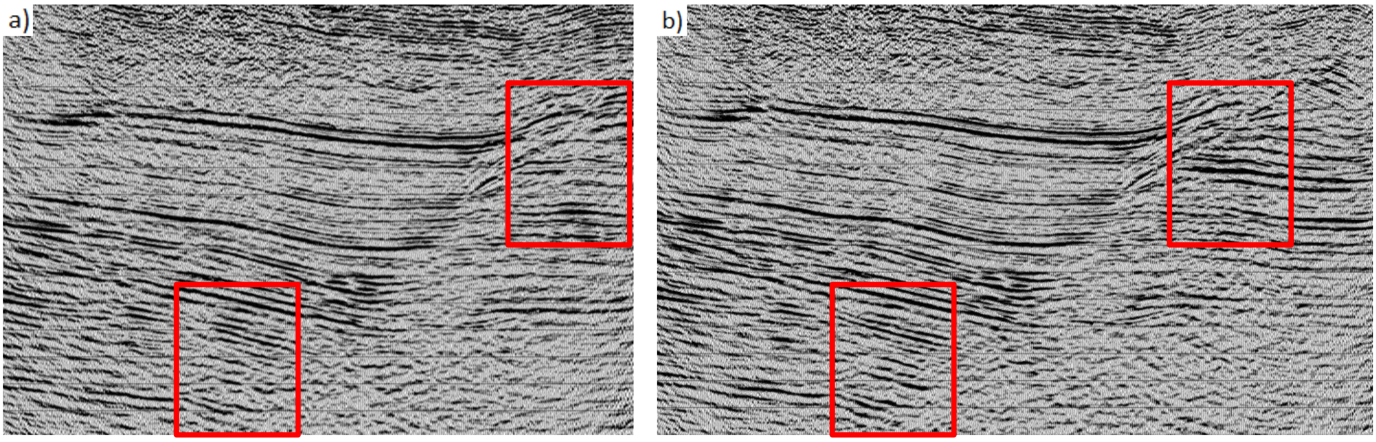


***Figure 3 : effect of short offset acquisition on reflector identification. These migration sections were processed on-field with respectively a) 450m b) 1300m offset on the foot wall (East part of the fault)***

Regarding the processing sequence to properly migrate the data, the on-field preprocessing had shown good results when using the Pre Stack Time Migration.

PreSTM is a migration technique for processing seismic data in areas where lateral velocity changes are not too severe, but structures are complex. Time migration has the effect of moving dipping events on a surface seismic line from apparent locations to their true locations in time. The resulting image is shown in terms of travel-time rather than depth, and must then be converted to depth with an accurate velocity model. Figure 4 compare the Post Stack Time migration with the PreSTM. The red rectangles and arrows focus on enhanced reflector by PreSTM in the vicinity of the fault where the complexity of reflectors' geometry is the most critical.

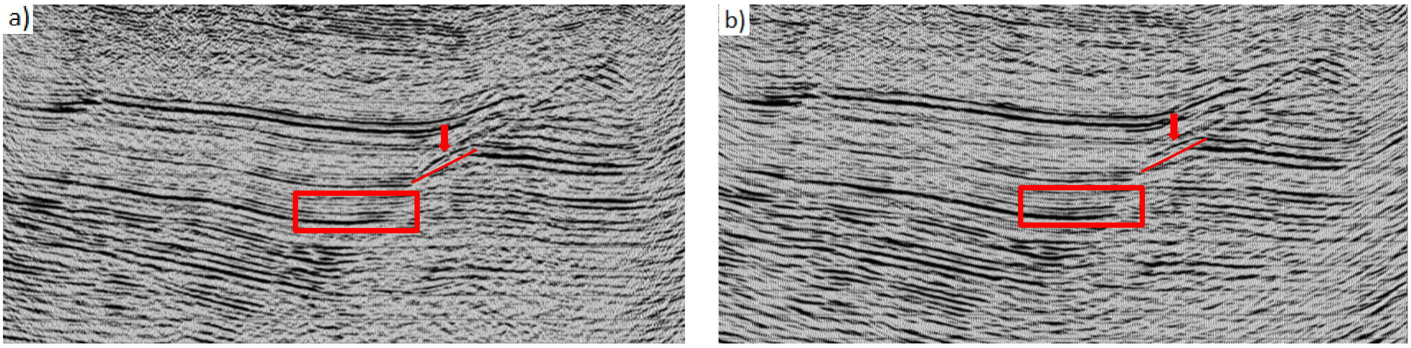


***Figure 4 : effect of seismic processing sequence on reflector position. a) Post Stack Time Migration b) Pre Stack Time Migration***

## Environmental and social constraints

Theoretical geometry designed at the very beginning of the survey cannot overcome on-field constraints in an urban context. Indeed, the exploration license overlaps some environmental restricted areas. For example, a part of the Illkirch forest is classified as National Nature Reserve and a large East part of the city is framed by a ZNIEFF (Natural Areas of Ecological Interest, Fauna and Flora) area.

In addition, much of the seismic acquisition devices have been deployed in the city. If the geophones deployment represents a very localized disturbance, the transit of the vibrator trucks was a real challenge both in terms of logistical and acceptability. Rural and urban acceptability studies regarding deep geothermal projects are quite recent in France (Lagache et al., 2013).

***Figure 5 : Booth with all seismic equipment during the local market***

However, the development of a geothermal project has to be a marker of participatory democracy. Indeed, even if the project is subject to an official public inquiry, the ES Group decided to have an early informative and sharing approach.

In that way the ES Group presented at the market of Illkirch-Graffenstaden, all seismic equipment prior to the acquisition and specialized engineers was there to answer citizen's questions (Figure 5). In addition, an informative letter explaining the exploratory phase of the project was sent to all residents affected by the transit of vibro-seismic trucks.

Before the acquisition, specialists in acoustics and vibration from APAVE undertook measures to qualify the vibration characteristics emitted by the trucks (Figure 6).

Safe distances and maximum vibration powers to respect were enacted. Moreover, to reduce vibrations disturbance, the ES Group decided to use only one truck in the city (Thacker et al., 2014).

And finally, during the acquisition, a real-time monitoring of each vibrated point was done at the nearest house to ensure that the vibrations emitted do not exceed the safety standards recommended by the APAVE.

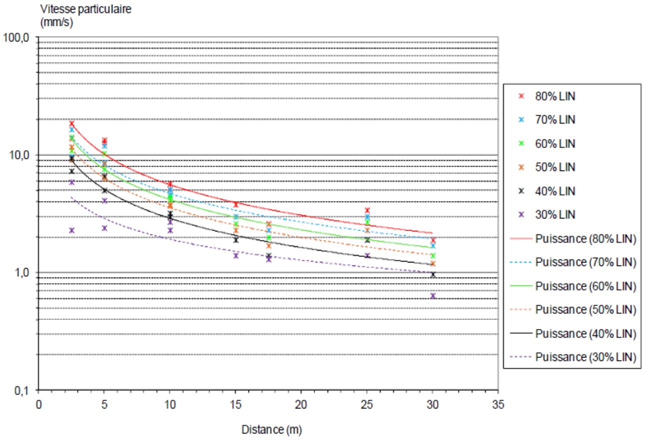


*Figure 6 : Particles velocity in function of the distance and the "Drive Level"*

## Conclusion and ongoing work

One of the most valuable geophysical methods to image fractured/faulted geothermal targets at great depth remains seismic reflection. However, the success of such exploration depends strongly on the horizontal and vertical resolution obtained with the defined acquisition parameters.

The seismic reflection newly acquired would provide all necessary information in term of geometry design, acquisition parameters, source power and processing sequence to correctly model fractured reservoir for future EGS high temperature exploitation in Alsace. In particular, this campaign will precise the litho-structural framework of the Illkirch EGS project allowing to better locate the target and to precise the trajectories of the wells.

The good practice used in the achievement of this survey regarding environment, academics cooperation, citizens care and risks monitoring could also contribute to improve the acceptability of the project, and more generally of geothermal EGS projects located in urban areas.

## References

Bouska J., 1997. *Sparse 3D, what's in a name?* Canadian Society of Exploration

Dezayes C., Genter A., Valley B., 2010. Structure of the low permeable naturally fractured geothermal reservoir at Soultz

Genter A., Cuenot N., Graff J.J., Schmittbuhl J., Villadangos G., 2015a. *La géothermie profonde en France : quelles leçons tirer du projet pilote de Soultz-sous-Forêts pour la réalisation d'un projet industriel à Rittershoffen* ? Revue Géologues, n°185, 97-101.

Genter A., Vidal J., Baujard C, Dalmais E., Schmittbuhl J., 2015b. *Permeability in deep-seated granitic rocks: lessons learnt from deep geothermal boreholes in the Upper Rhine Graben,* Vingtièmes journées techniques du Comité Français d'Hydrogéologie de l'Association Internationale des Hydrogéologues. Aquifères de socle: le point sur les concepts et les applications opérationnelles

Lagache L., Genter A., Baumgartner J., Kolbel Th., Villadangos G., 2013. *The first acceptability study of an EGS plant in Northern Alsace*, Third European Geothermal Review (TEGR)

Lavergne M., 1986. *Méthodes sismiques*, editions TECHNIP

Ourabah A., Grimshaw M., Keggin J., Kowalczyk-Kedzierska M., Stone J., Murray E., Cooper S. , Shaw L., 2014. *Acquiring and Imaging Ultra High Density Land Seismic Data - Practical Challenges and the Impact of Spatial Sampling*, 76th EAGE Conference and Exhibition

Thacker P., Harger D., Iverson D., 2014. *An evaluation of single vibrator, single sweep, 3D seismic acquisition in the Western Canada Sedimentary Basin*, Canadian Society of Exploration

Talagapu K. K., 2005. *2D and 3D Land Seismic Data Acquisition and Seismic Data Processing*

Yilmaz O., 1987. *Seismic Data Processing (Investigations in Geophysics, Vol 2)*, Society of Exploration Geophysicists

Yilmaz O., 2001. *Seismic data analysis*, Society of Exploration Geophysicists