

Geoscan Île-de-France: Integrating New and Vintage Data to Foster Development of Deep Geothermal Projects.

Introduction

Geothermal energy is a well-established and promising form of renewable energy that plays a critical role in meeting carbon emissions reduction targets and improving the renewable energy mix in urban areas. It stands among the most stable and non-intermittent source of energy characterised by low carbon emissions, local production and consumption and allows energy cost to be controlled for end users. In France, deep geothermal energy is mainly used for direct heat use with significant development concentrated in the east and north of the Île-de-France region since the 1970s. Accounting for more than 80% of national heat production, the Île-de-France region has the highest density of geothermal urban heating networks in Europe, with 1.94 TWh of heat production in 2023 and 55 active installations. The quality of the main targeted reservoir in the Paris basin, the Dogger formation dating from the middle Jurassic, with temperature from 55°C to 80°C and highly permeable layers, has been a key factor in the development of the geothermal energy in this densely populated area.

However, the number of installations in the western and southern parts of the region remains relatively low despite a high demand for heating in this large urban area. This is largely due to the limited knowledge of the subsurface and the perceived less favourable conditions for geothermal resources development in comparison to the well-known and developed eastern and northern areas. This area includes large urban areas with high heat demand and more than 30 geothermal prospects have been identified in the zone, with several wells currently being drilled or planned for development in the coming years, all of which face significant geological uncertainties.

To meet these challenges, the Agency for Ecological Transition (ADEME agency), the Île-de-France Regional Council and the French Geological Survey (BRGM) have launched a deep geothermal exploration campaign in this area of the south and west of Paris, covering almost 2 000 km². The aim of this programme is to improve the subsurface knowledge and provide valuable information over the different aquifers present underground to reduce the existing uncertainties and facilitate the development of geothermal projects in the region. The program consists of several components: from geophysical data acquisition and processing, reprocessing of vintage seismic and well data, to structural and quantitative interpretation. The final objective is the integration of all elements produced and analysed to generate a geological model of the area and predict reservoir properties over different deep reservoirs targeted (Albian, Neocomian, Oxfordian, Dogger and Triassic, see Figure 1.B).

The dataset and processing

A large dataset of existing vintage seismic reflection data, geothermal wells and hydrocarbon wells, has been collected across the region, mainly from oil and gas exploration in the 1960s and 1980s (cf. Figure 1.A). This dataset provides an excellent coverage of the area of interest allowing a relatively dense spatial sampling for structural interpretation, which is usually the standard in the geothermal industry. Allo et al. (2021) showed that despite the limited quality of the vintage seismic data in terms of frequency content and resolution, a quantitative interpretation provides additional information on the reservoir properties.

Amplitude preserving reprocessing of 1660 km 2D present in the zone of interest has been carried out to enable the quantitative interpretation of the data. This reprocessing has never been carried out at such scale and for geothermal exploration purposes in this region.

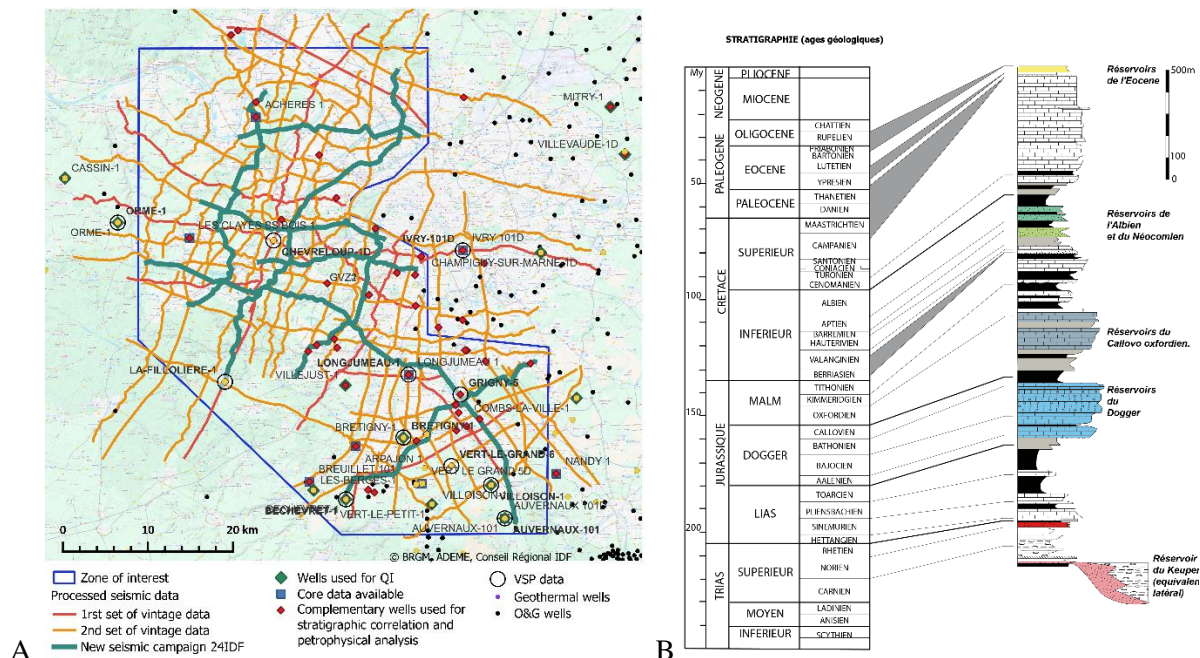


Figure 1. Map of the Geoscan Ile-de-France project perimeter with indication of vintage seismic lines and new seismic acquisition available (A) and summary stratigraphy of the Paris sedimentary basin (B) from BRGM and Guillaucheu et al. (2000)

Seismic acquisition has progressed tremendously since the 1980s in terms of spatial sampling and frequency content allowed. These advances, and in particular the ability to acquire broadband data (Baeten et al 2010) have a positive impact on impedance inversion (ten Kroode, 2013). For these reasons, the programme also included the acquisition of a new state-of-the-art 2D seismic survey over 280 km (Figure 1.A).

The new seismic reflection lines (Maurel et al., 2024) were acquired with a broadband frequency sweep of 48s ranging from 2 Hz to 96 Hz. The receivers are wireless accelerometers spaced 20 meters apart. The source is a single vibrator with a maximum output of 65 000lbs with an interval of 10 m. The use of random sweep allowed the acquisition of a given line with three vibrators. The acquisition took place at night, which drastically reduced the recorded noise.

The data was processed using the same amplitude preserving processing sequence as the legacy data, with exception of the ground roll removal procedure, which is adapted to a single sensor. The imaging step consists of Pre-Stack Time-Migration, as the lateral and vertical velocity variations are too mild to require the use of a depth velocity model. Mild post-processing steps are applied to the stack to improve the data. In addition, new petrophysical measurements have been made over the core data.

The importance of new dataset

The locations of the new line were chosen to fill in gaps in the legacy data, but for one line we use a similar path over a short profile to highlight the added value of the modern data (Figure 2.B). The image from the legacy data (Figure 2.A left) is clearly inferior compared to the modern data (Figure 2.B right) which has clearly distinguishable reflectors and higher resolution. The corresponding amplitude spectrum (Figure 2.C) shows that we have added two octaves in the low frequencies and almost an octave in the high frequencies. The recorded low frequency signal will be essential for quantitative inversion.

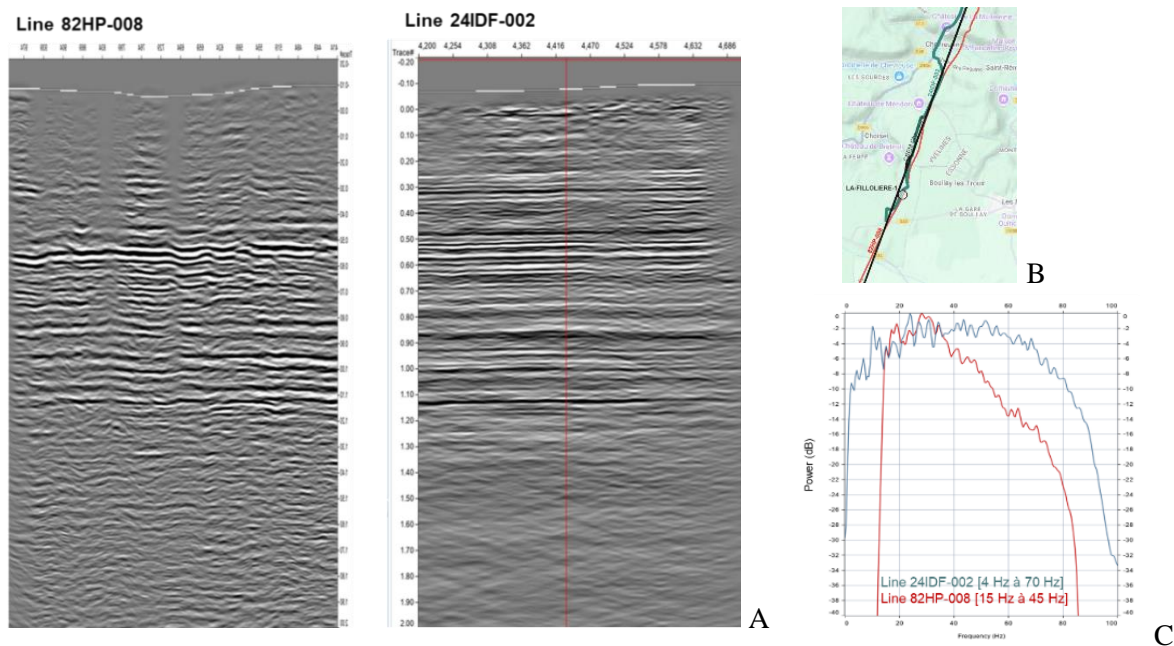


Figure 2. Comparison of PSTM treatment for a vintage line 82HP-008 and a new seismic acquisition 24IDF-002 (A). The lines are parallel one another in the sector of Choisel, southwest of the studied area - in green line 24IDF-002, in red line 82HP-008 (B) and comparison of the frequency spectrum of line 24IDF-002 and 82HP-008 (C).

Methods for quantitative analysis

Both vintage and new 2D seismic datasets, along with well logs from 10 wells, were used to predict petrophysical properties (total porosity, clay volume and permeability) along the 2D seismic lines. A rock physics-guided machine learning approach (Downton et al., 2020), enabling direct prediction of target properties with associated uncertainty estimation, was applied. The workflow comprises two major steps: augmentation of the training data (synthetic catalogue generation) and neural network training and application.

Synthetic catalogue generation involves rock physics model creation, statistical analysis, and scenario modelling to account for expected property and thickness variation at the zone of interest. Given the complex geological settings, which include a mixture of carbonate and clastic formations, different rock physics models were developed and calibrated for various facies. These calibrated models, combined with statistical analysis (mean and variance for each lithological layer), were used to model scenarios by varying the thickness and petrophysical properties of the target layers. Hundreds of pseudo-wells were simulated, and synthetic seismic gathers were generated for each well, forming the synthetic catalogue.

Convolutional neural networks were then trained on the synthetic catalogue to predict total porosity and clay volume. A transfer learning step was subsequently applied to incorporate the effects of real seismic data, enhancing the prediction results. Finally, permeability was calculated from the total porosity and clay volume by applying different empirical relationships tailored to different layers. The result of the petrophysical properties prediction for one of the 2D lines is shown in the Figure 3.

The estimated rock properties match the overlaid log data of two wells: VILLOISON-1 and AUVERNAUX-101. Sweet spots for geothermal reservoirs are zones with high porosity, high permeability, and low clay content.

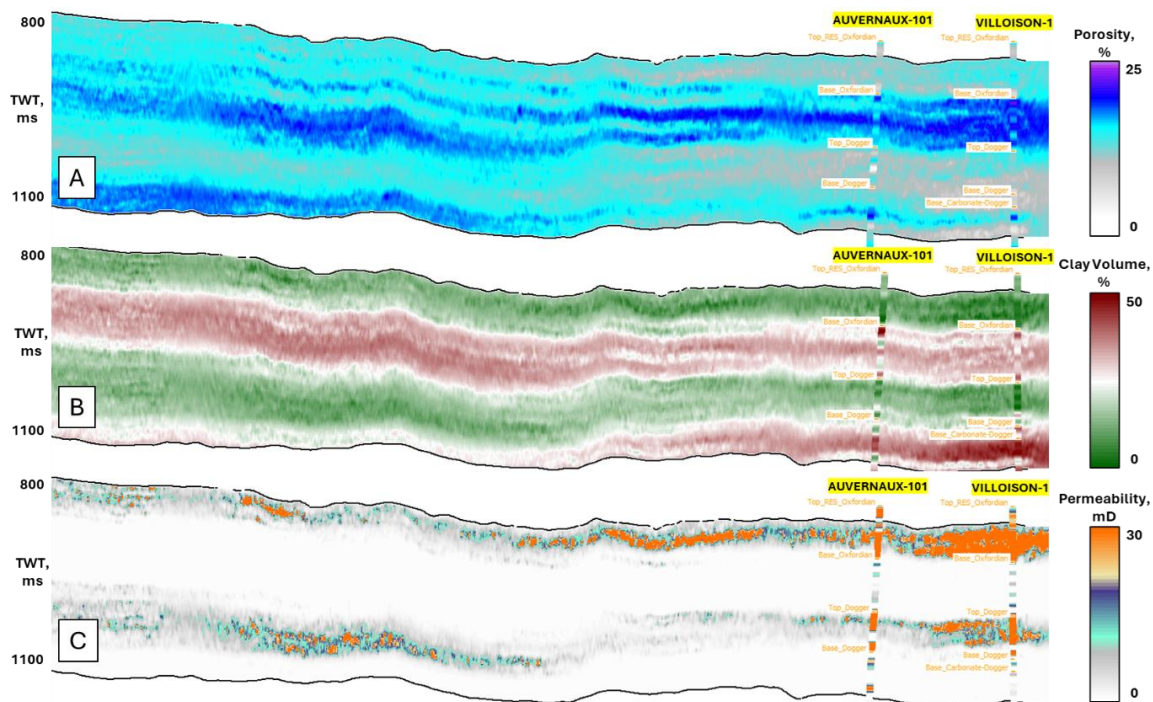


Figure 3. *Petrophysical properties prediction result: Total Porosity (A), Clay Volume (B), and Permeability (C).*

Conclusion

An exploration campaign covering 2000 km² on the South and West part of Paris has been carried out to help with geothermal exploration. Integration of legacy and modern seismic and well data, reprocessing and quantitative interpretation is part of the program. The preliminary results reveal the position and extent of layers that could prove to be favourable for future geothermal wells in the area. The method will be applied to the entire seismic survey of 2024 and to vintage dataset over the area of interest. The program should help decision-making, minimizes exploration costs, and promotes sustainable geothermal resource development in the South and West of the Île-de-France region.

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