Deliverable 2.3

Seismic acquisition for Paris Basin plus survey results and interpretation

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PilotSTRATEGY (H2020- Topic LC-SC3-NZE-6-2020 - RIA)

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1. Document History

1.1. Location

This document is stored in the following location:

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Location	https://pilotstrategy.eu/about-the-project/work-packages/geo-characterisation

1.2. Revision History

This document has been through the following revisions:

Version No.	Revision Date	Filename/Location stored:	Brief Summary of Changes
Draft1	10/03/2023	Sharepoint/WP2/task2.2	
Draft2	20/03/2023	Sharepoint/WP2/task2.2	Address comments from WP leader review
Final Version	28/03/2023	Sharepoint/WP2/task2.2	

1.3. Authorization

This document requires the following approvals:

AUTHORISATION	Name	Signature	Date
WP co-Leader	Francisco Pángaro Bedoya		28/03/23
Project Coordinator	Fernanda de Mesquita Lobo Veloso		28/03/23

1.4. Distribution

This document has been distributed to:

Name	Title	Version Issued	Date of Issue
		PUBLIC	00/00/0000

The PilotSTRATEGY project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101022664

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2. Executive summary

This deliverable is a detailed report of the 3D seismic acquisition conducted in the Paris Basin – Grandpuits area for the PilotSTRATEGY project and preliminary seismic interpretation.

A full detailed explanation of the workflow and parameters used for seismic acquisition is presented in the current report. Design, permitting, acquisition, quality control and pre-processing of the campaign were carried out by Smart Seismic Solutions (S^3), third party partner of the project, from December 2021 to July 2022. The acquisition itself (layout of the receivers, vibration, collection of the receivers) took place over a period of only 5 weeks from mid-May until the end of June.

The permitting operations, or application for approvals of passages, started on April 11 and ended on May 10. 2 people were responsible for the requests, while 2 distributed the project information flyers to all the mailboxes of all the villages affected by the project. Nearly 10,000 flyers were distributed. In total, 84 farmers were contacted, 63 gave us permission to position our sensors in their plots and 16 farmers refused our passage despite various interventions, including serious support from the BRGM.

The 16 farmers who refused passage in their plots represent about 20% of the total area of the project. Nevertheless, we were able to position our sensors on the public domain between their plots which limited the loss of geophysical data.

A total of 6 vibrator trucks of 2 different models were used on this project to meet all constraints (sensitive structures, manoeuvrability in urban areas, noise constraints, cultivated areas, etc.). 2 types of "node" type sensors were used: Wing and RAU (Recording Acquisition Unite) both from Sercel. A total of 4451 RAUs and 491 WINGs were deployed in 12 days

Permitting was one of the main challenges of this project, as is often the case in this type of urban/rural project. Zones marked as 'NO GO' specifying a ban on driving with vibrators were communicated and checked daily.

The large volume of data (10TB) was processed to transform the raw data into a 3D image of the subsurface for geological seismic interpretation.

The preliminary interpretation of the seismic data along the full sedimentary pile indicates the high potential of this data for the understanding of the reservoir for CO_2 storage. Detailed work on other data such as thin section, cores, well logs, and well log / seismic attributes comparison will allow us to have a better understanding of the reservoir complex and propose a precise interpretation of the targeted reservoir.

All these elements will feed into the rest of the project, allowing the building of a reservoir model; understanding the storage capacity and injection strategy; evaluating the integrity of the caprock; and finally proposing a concept for the development of the pilot.

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3. Introduction

3.1. General Information

The project "CO2 Geological Pilots in Strategic Territories (pilotSTRATEGY)", is a European Project in the framework of the 2020 Horizon call (CALL H2020-LC-SC3-2018-2019-2020).

The objective of the project is to present a proposal for the development, monitoring and implementation of three pilot sites for CO_2 storage in France, Portugal and Spain, and in lesser detail, in Poland and Greece. The proposal, one site for each country of the three main regions, will be based on the detailed geological characterization of the structure, static and dynamic modelling, the detection of associated risks, and social engagement. The project is presented as a continuation of the STRATEGY CCUS (2019-2021) of the H2020.

Among the priority works in the French Region – Paris Basin is a geophysical acquisition campaign of the seismic reflection type with the aim of imaging the subsurface to a depth of the order of 3 kilometers, thus allowing a better understanding of the structure of the subsurface and the potential of the sector. The 3D seismic reflection study covers an area of 111 km², located mainly in the territory of Brie Nangissienne in the Val de Marne (77).

Figure 3-1: Location map of the area of interest

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Coordinates of the polygon (Lambert 93)

	x	y
A	691600	6828200
B	691600	6839600
C	702250	6839600
D	702250	6828200

Acquisition of 3D seismic data is regularly used to find oil and gas, but outside of this its use is not common, as acquiring data can be a costly exercise. A recent development in acquisition technologies allows us to acquire more data in a shorter time, using an independent and autonomous fleet of single vibrators. This unique technology, called SRS (Simultaneous Random Sweep), is implemented by Smart Seismic Solutions (S^3) and brings two main advantages.

- A much higher density of records (enhanced resolution)
- A greater social acceptability by the local population (faster acquisition with smaller teams)

3D seismic acquisition with SRS technology was used in France for the first time in 2018, as part of geothermal exploration in the North-East of country and had a proven impact on local reservoir imaging. Since then, the technology has been successfully deployed in France for new local energy exploration (such as helium) and is being considered by many new sectors. The use of novel technologies like SRS acquired mainly on public roads, and a design with sparse receiver coverage, has helped reduce the overall cost.

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1.1 Environment

Topographically, the whole area is low relief.

The study area mostly covers agricultural areas around Grandpuits. The urban part (representing ~2% of the study), consists of 16 cities or villages. These several villages allow access to many roads and paths through the project. A wooded area representing 10% of the project area is mainly located southwest of the study block. It is worth noting the presence of several industries: the Total refinery, the Borealis fertilizer plant and the Lesaffre sugar factory.

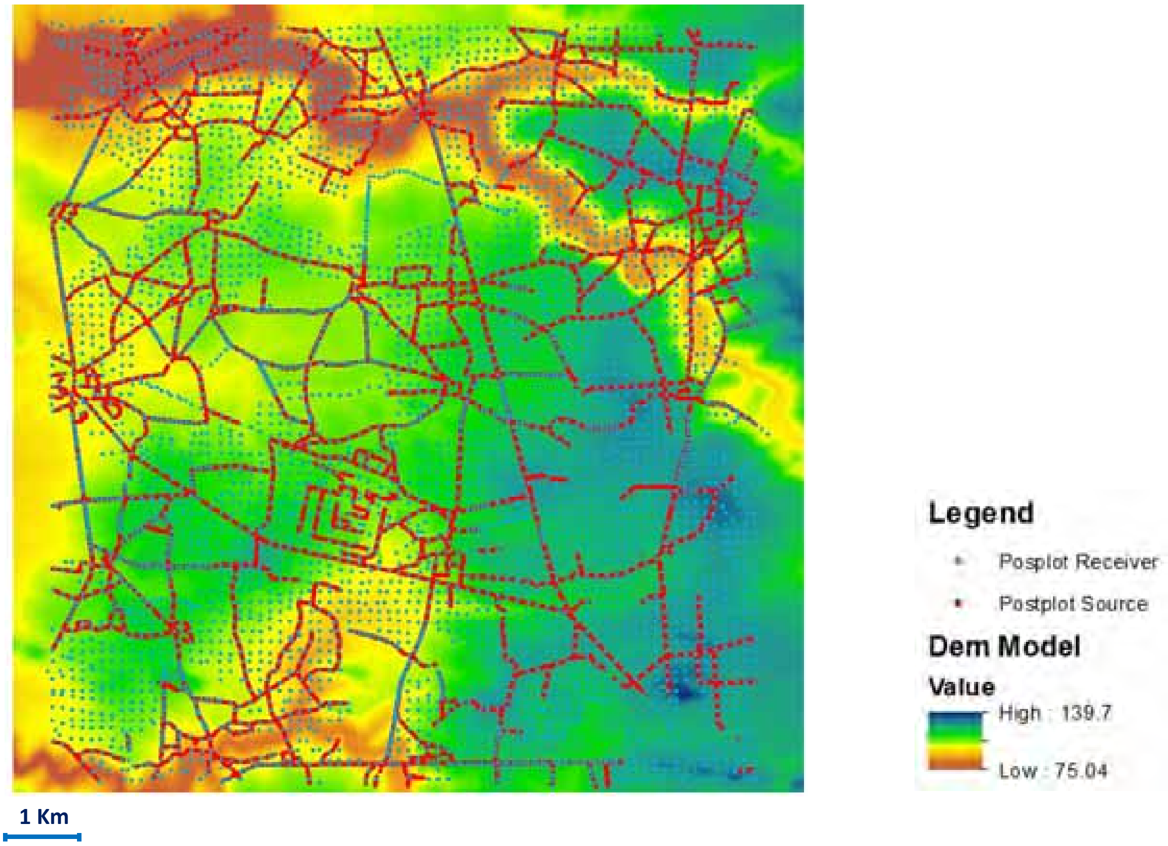

Figure 3-2 : Digital Elevation Model of studied area (see Figure 3-1) with the position of receiver and sources used for the seismic acquisition.

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Terrain type	Land quantity	Area (Km²)
Villages and cities	280	1,6
Crops	1359	97,8
Woods	114	11,4
TOTAL	1753	110,8

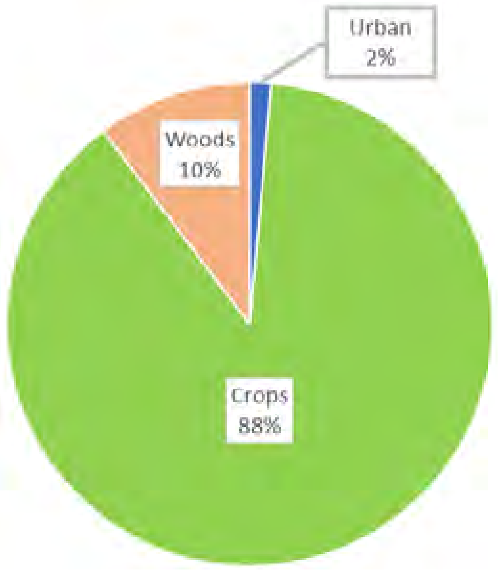

Figure 3-3: Breakdown of surfaces by type of land

Field operations were not subjected to harsh weather conditions. There were only a few days of precipitation. The rain that fell during the acquisition operations affected the signal/noise ratio, resulting in an additional period of acquisition at the end of the project in some zones.

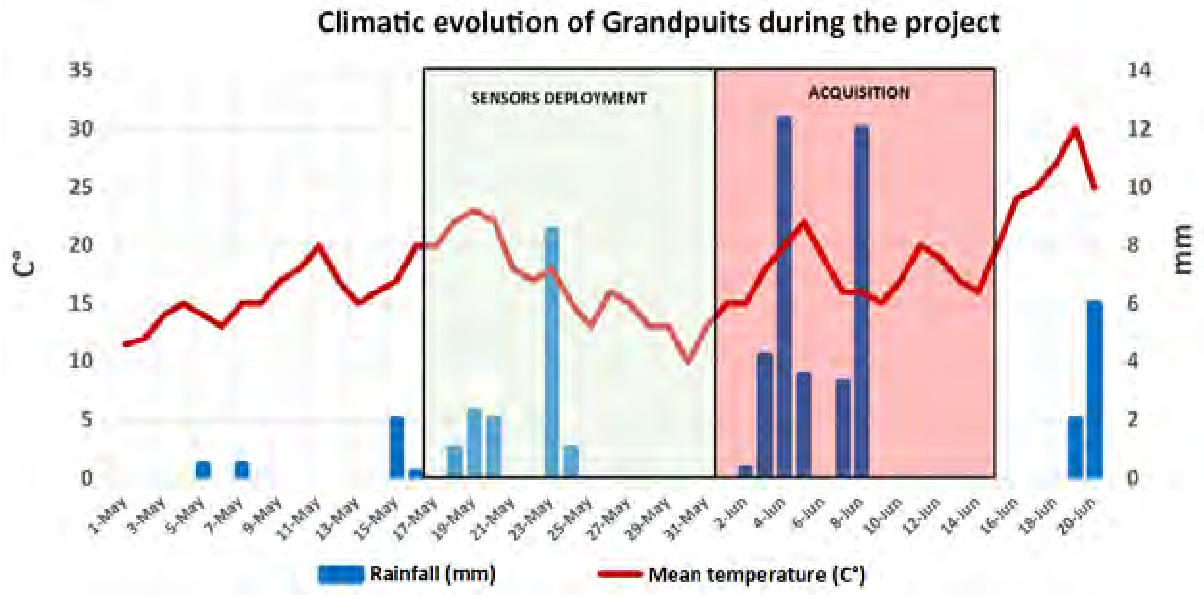

Figure 3-4: Influence of precipitation on acquisitionLogistic and organization

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3.2. Organizational chart

3.3. Main suppliers

- GEOTEC : Supplier of vibrator equipment and personnel
- QAPA: Recruitment & Human Resources Management
- SERCEL : Supplier of seismic equipment

GEOTEC SPA
QAPA La solution digitale Adecco

3.4. Infrastructures

The main base and parking (~2000m² with 15 parking spaces) was located east of Grandpuits. This allowed us to have a central position in relation to the study block. This base included an open shed for the storage of crates and the maintenance of vibrators, and a closed part including the recording workshop. The QC (quality control) and management/HSE offices were located at the Refuge de Grandpuits campsite. All the staff were housed at the IBIS hotel in Melun.

Figure 3-5: Location of logistical infrastructures

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Figure 3-6: Base infrastructure

Figure 3-7: Parking for the operations vehicles

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Figure 3-8: Maintenance hangar and vibrators

Figure 3-9: Data acquisition and processing workshop

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3.5. Human ressources

Team composition:

DEPARTEMENT	FONCTION	QUANTITÉ
MANAGEMENT	Party chief	1
	admin	1
	HSE/LTC	1
TOPO	HOD Topo	2
	surveyor	3
RECORDING	Recording Manager	1
	Observer	1
	Line Boss	1
	Sensors Deployment	18
	Line Checkers	3
	Work shop chief	1
	Work shop assist	2
VIBRATEURS	Mecha HOD	1
	Prod manager	1
	mechanical	2
	Pilotes	6
	Vib Pushers	6
	Traffic manager	4
QC	Preplanning	1
	Prod manager	1
	Processing	1

Workforce evolution:

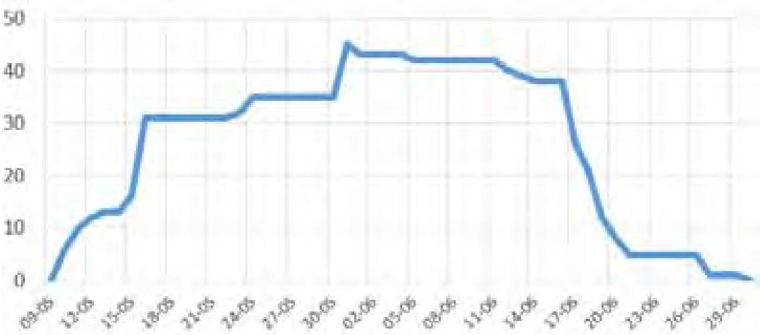

Figure 3-10: Workforce evolution

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3.6. Transport

QUANTITY	BRAND	TYPE
2	RENAULT	KANGOO
18	TOYOTA	HILUX

A total of 18 cars were mobilized.

The Land Transport Coordinator (LTC) was in charge of vehicle management, drivers and safety, as well as driver training.

3.7. Operational Schedule

The operation comprises eight key steps: Permitting preparation (Authorization documents, contacts and field survey); Meeting with municipalities and farmers; agreement with farmers and owners to install receivers and vibration points; Data acquisition; receivers pick up from field; compensations and data processing.

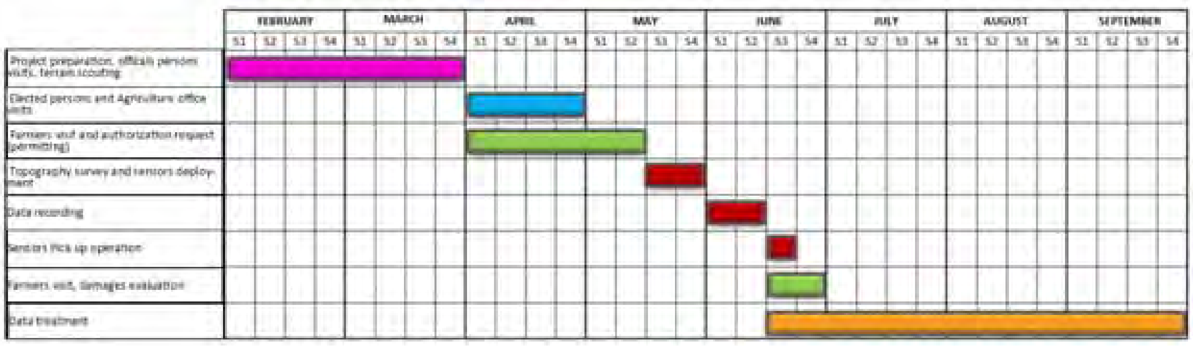

Figure 3-11: Planning of Operations and schedule of main steps during the operation

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4. Acquisition parameters

4.1. Geodesy

Table 4-1: Geodesy data

Name	**Lambert 93**
WKID	2154 Authority: EPSG
Projection	Lambert Conformal Conic
False Easting	700000.0
False Northing	6600000.0
Central Meridian	3.0
Standard Parallel 1	44.0
Standard Parallel 2	49.0
Latitude of origin	46.5
Linear Unit	Meter (1.0)
Geographic Coordinate System	GCS_RGF_1993
Angular Unit	Degree (0.0174532925199433)
Prime meridian	Greenwich (0.0)
Datum	D_RGF_1993
Spheroid	GRS_1980
Semimajor	6378137.0
Semiminor axis	6356752.314140356
Inverse flattening	298.257222101
Geoid model used	RAF09

Table 4-2 Geodesy Parameters

Points de contrôle IGN - RTK

	Standard Dev	0.002	0.001	0.003	0.003
RTK Premium S³	Moyenne	698745.611	6831213.761	170.047	125.808
IGN	IAG GRS 1980	698745.600	6831213.850	170.030	125.772
Delta		0.011	-0.089	0.017	0.036

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4.2. Geometry

Table 4-3: Data geometry of receivers and sources points

Receivers quantity	5544
Receivers quantity per line	72
Receivers line interval	150 m
Receivers interval	150 m
Source points quantity	30 000
Source points interval	11 m
Bin size	30 m x 30 m
Active Spread	100 %

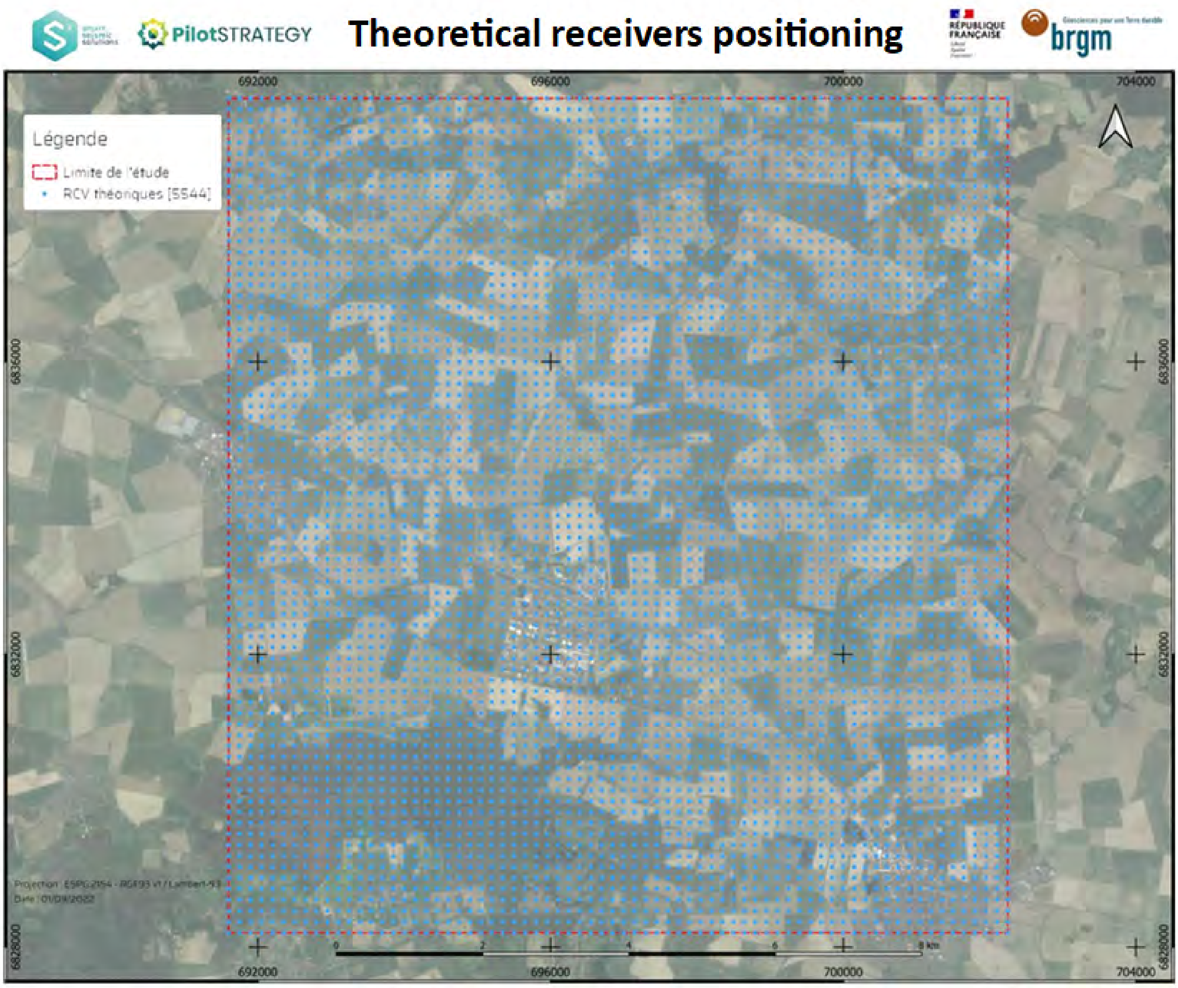

Figure 4-1: Theoretical representation of sensors

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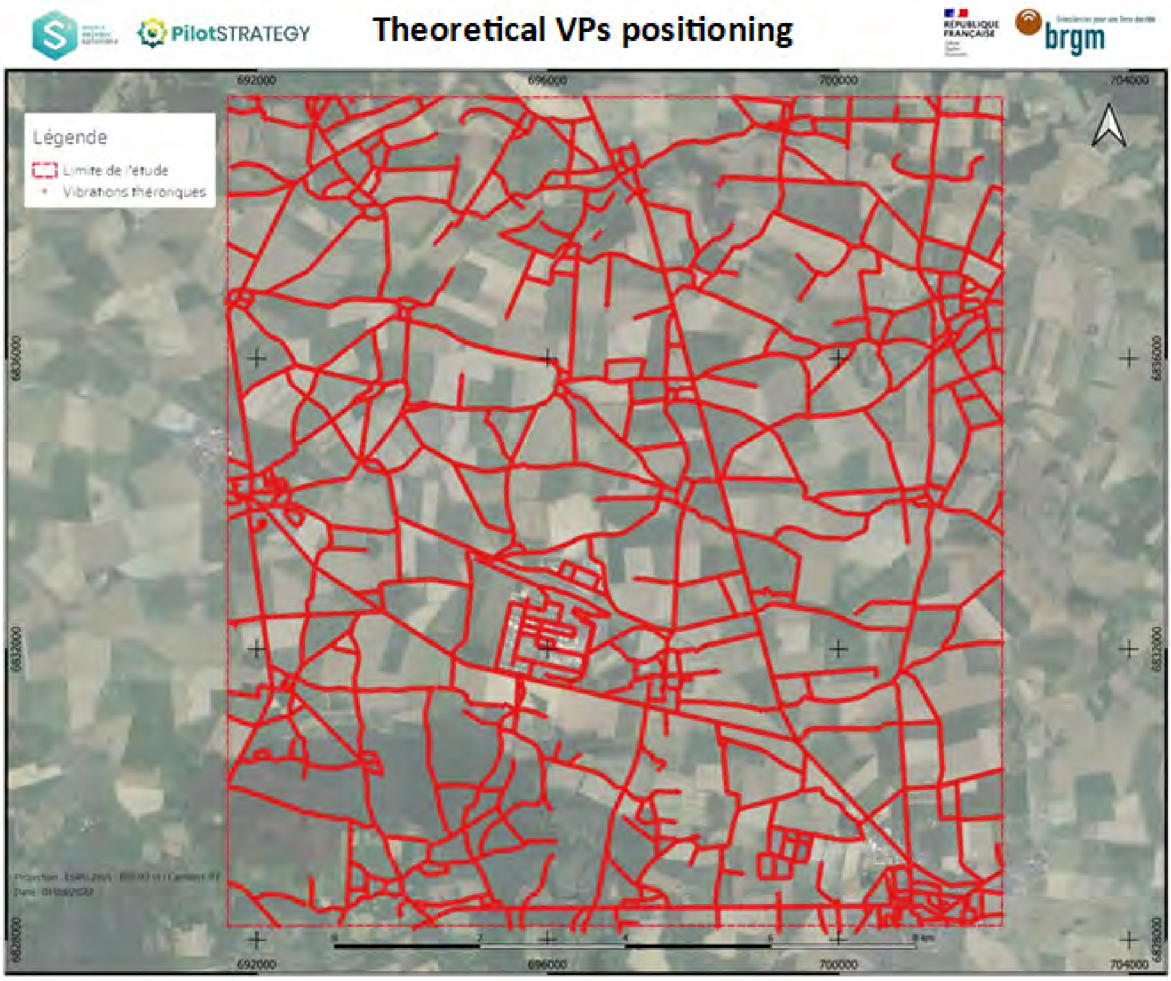

Figure 4-2: Theoretical representation of source points

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4.3. Acquisition parameters

Recording parameters:

	RAU	WINGS
Sampling	2 ms	2 ms
Sampling maximum frequence	250 Hz	250 Hz
Recording type	Continu	Continu
recording lenght	2 min	2 min
Filter	Minimum phase - High Cut 0.8 Nyquist	
Signal Gain	12 dB	0 dB
Recording time	8h – 18h	
Data type	SEG D	SEG D
ID seismic recording	Starting from 00010001.segd	Starting from 00100001.segd
Data transfert	Hard disks (NAS)	

Sources parameters:

Vibrators quantity	**4 x M26** **2 x PRAKLA**
Vibration per day per vibrator	360
Vibrator quantity per vibrated point	1
Acquisition type	SRS (Simultaneous Random Sweep)
Sweep type	Random
Sweep's frequency range	3-90 Hz
Sweep lenght	30 seconds
Drive level	80% (40 % in urban area)
DGPS (RTK)	Yes

5. Acquisition pre-planning

5.1. First step

We performed a theoretical positioning of source points and receivers in early February 2022. The first task was to remove all the source points from the cultivated fields in order to reduce our impact and facilitate requests for passages from farmers.

The receivers were moved as much as possible along the roads and paths. Those located in the fields were placed in situ along the farming tractor driving paths The vibrated points (VPs), were placed on the roads and paths.

Obstacles such as underground networks or sensitive structures have been taken into account via the DT & DICT process (Request for Works, Declaration of Intent to Start of Work).

258 DT & DICT requests were made in order to obtain the plans in digital formats of the different networks (water, gas, hydrocarbon). This vector data recovery process is very long and requires a lot of preparation and organization. Indeed, the receipts received following the deposit of DT & DICT include pdf plans that are not usable as is. We must therefore contact all the service providers in order to obtain the vector data to be able to integrate the necessary safety distances on each type of obstacle.

Once all this information was available on our GIS, we refined the pre-planning so as not to vibrate in these buffers and not to damage the various underground structures. When the vibrated points could not be moved, they were either skipped or vibrated with a force reduced to 40%.

The strategy for source points was to create points every 11 metres on all roads and paths within the acquisition range. This number reaches 35395 VPs (about 20% more than initially planned). Indeed, at this stage, we did not yet had all the authorizations of the operators as well as the data concerning the gas, hydrocarbon water networks and the communal and private roads.

The Figure 5-1 represents the theoretical RCV/SRC positions as of 02/05/2022.

The Figure 5-2 map shows the offset minimums on the project during the pre-plan phase. The areas in red correspond to the areas without roads and therefore in which we cannot vibrate.

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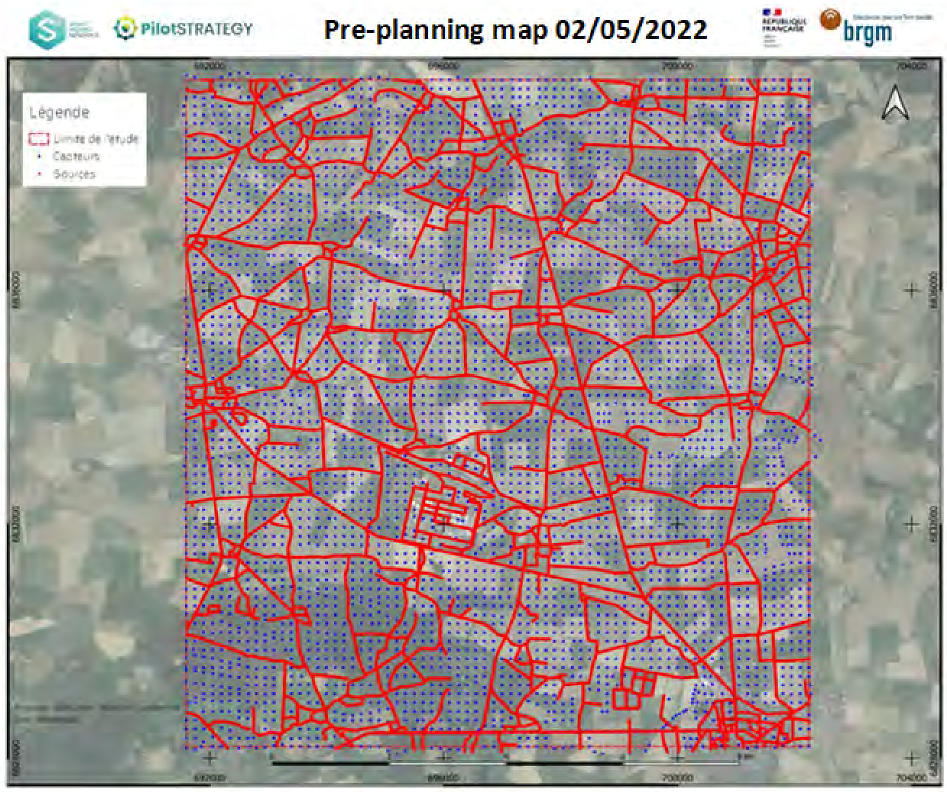

Figure 5-1: First step of the pre planning

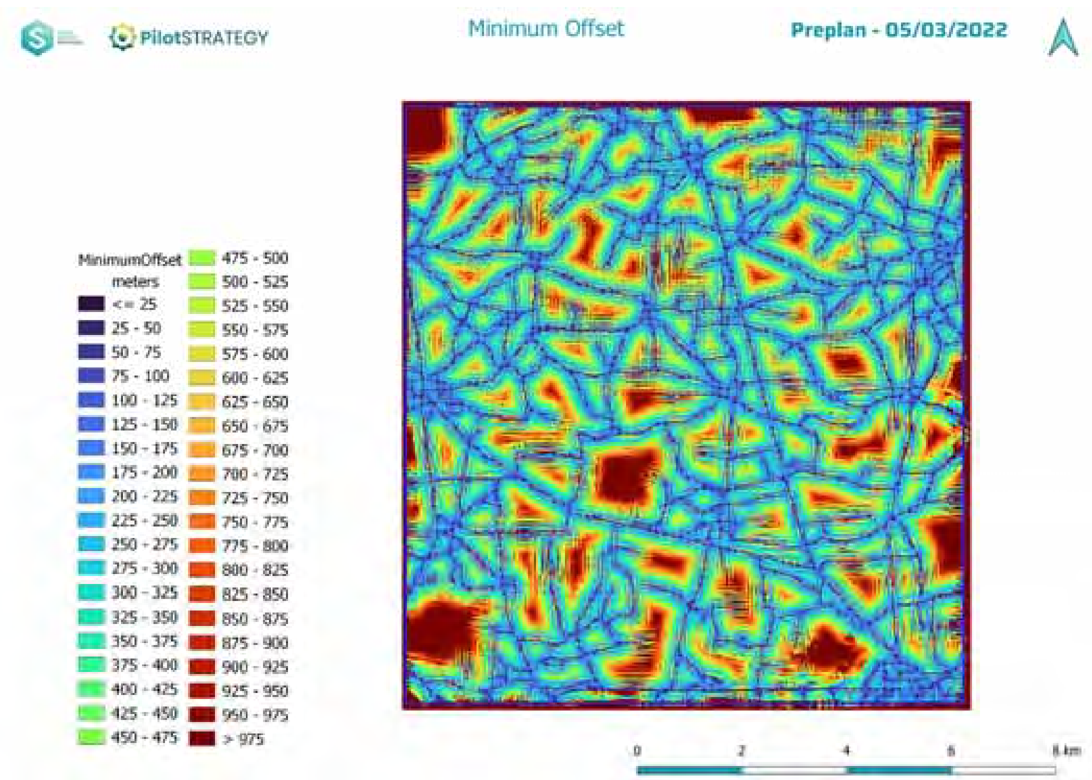

Figure 5-2: First offset min map- 03 mai 2022. The areas in red correspond to the areas without roads and therefore in which we cannot vibrate.

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Subsequently, some areas will be available such as the refinery at the center of the project and the LESSAFRE plant. We also had farmers who eventually denied us access to their private fields and roads, which had a negative impact on the data.

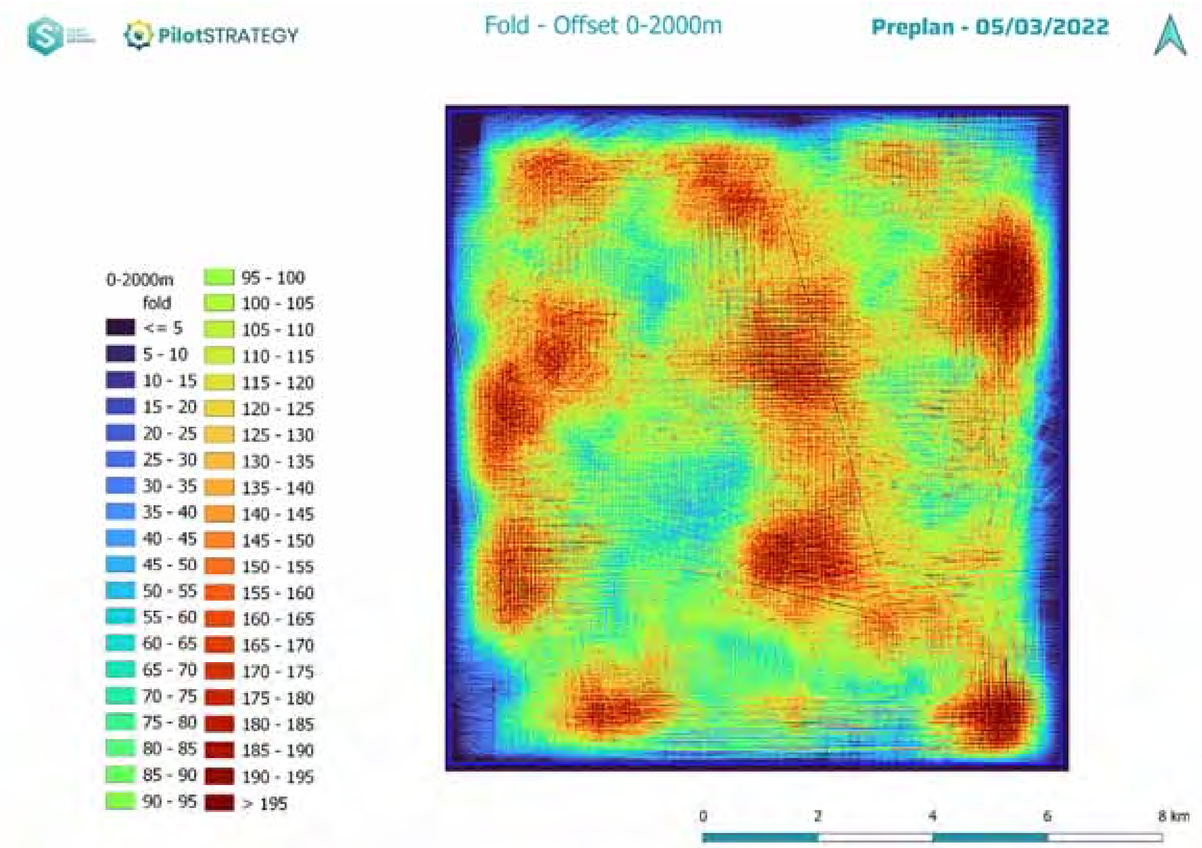

Figure 5-3: First fold map in the offset range 0 to 2000m - 03 may 2022

5.2. Methodology

The project pre-plan was carried out in close collaboration with the S3 permitting team. Every day, the permitting database was updated to refine the documents and the pre-plan of operations for sensors and vibrations.

Maps with sensor positions were updated daily so that the permitting team could show operators where the sensors will be located on their plots. After making appointments with farmers, modifications could be made to meet the demands of farmers. Figure 5-4 is an example of a map provided to be able to present the position of the sensors and the passages of the trucks.

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Figure 5-4: Detail map with the position of receivers (blue dots) and vibration points (red dots)

This database also allowed us to retrieve information about crops to be able to adapt the installation of sensors in the fields (barrel passage, high or low crop, presence of irrigation system etc.). All this information allowed us to be reactive if a farmer, for example, wanted to harvest on one of his plots because in this case we had to remove the sensors and put them back afterwards. Communication was the key to a successful operation. We tried to meet the expectations of all operators and react very quickly if problems arose. Thanks to this census, we also retrieved information about private and public roads.

5.3. Obstacles and safety distances

Here after a matrix of the safety distances used:

Table 5-1: List of safety distances put in place

Obstacle	Distance (m)
Countryside houses (Prakla vibrator)	Greater than 10 m
Countryside houses (M26 vibrator)	Greater than 20 m
Pipe lines SFDM- TRAPIL	11 m
Buildings classed as historical monuments	26 m
Church	26 m

Obstacle	Distance (m)
Pipes IPC	7 m
Gaz Pipes GRTGAZ/ Vermillon	6 m
Pipe lines Boréalis-Total	5 m
Water pipes	1 m
Urban houses (Prakla vibrator)	greater than 10 m
Urban houses (M26 vibrator)	greater than 20 m

If, however, source points were kept in the buffer zones close to the buildings, the vibrations were carried out with a force reduced to 40% of the maximum power (Low Drive).

PPV (Peak Particle Velocity) devices have also allowed us, mainly in urban areas, to meet building-related vibration standards. If these values exceeded the authorized threshold, the vibrated point was immediately stopped and skipped. The fixed value was 4mm/s. This value is set to maximize the number of points that can be performed near buildings. 3 mm/s being the limit for very sensitive buildings and 6mm/s for sensitive buildings.

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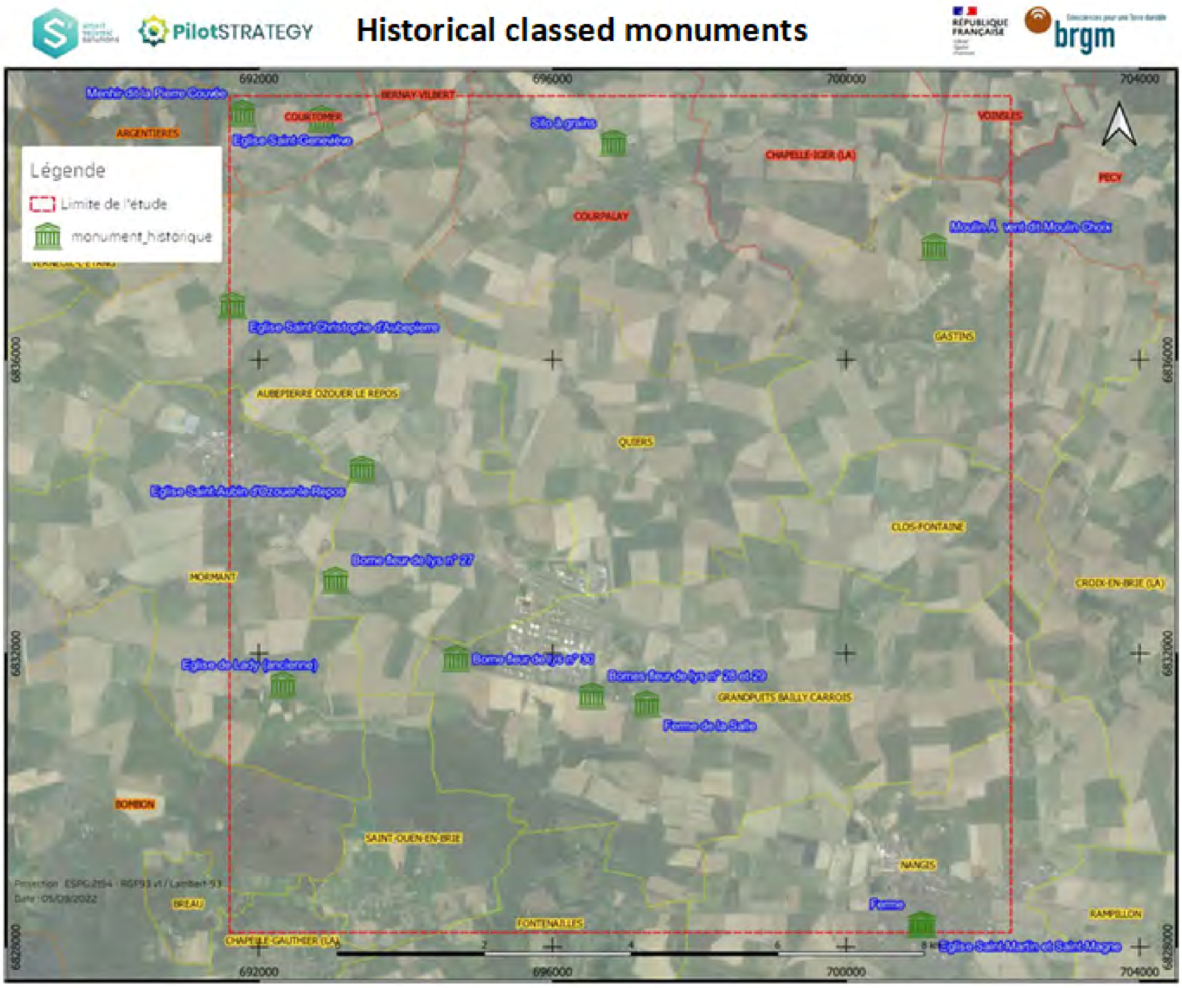

Figure 5-5: Historic monuments map

A much greater distance of 26 meters has been set up for the historic buildings which are displayed in figure 6-5.

This distance allows us to be sure to be well below the threshold of 3mm/s for very sensitive buildings.

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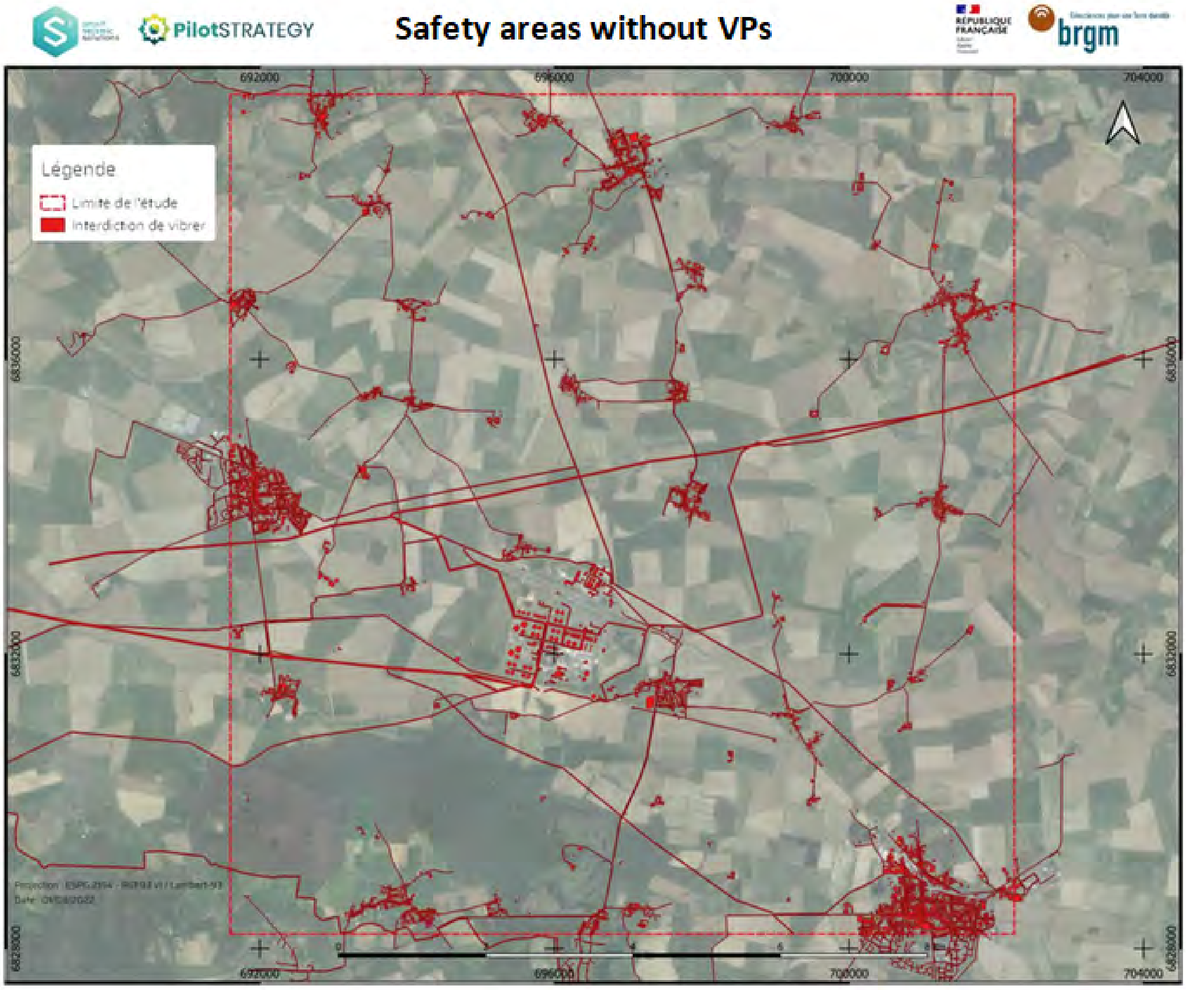

Figure 5-6: Obstacles and safety zones

5.4. Permitting

The only risk of damage caused by seismic activities is minimal damage to crops during the deployment of sensors, and the risk of soil compaction as on missions where vibrators operate in cultivated fields.

It was therefore necessary to focus requests for approvals of passages on the operators and not on the landowners.

To do this, the crucial information to be retrieved was a database specifying the location of the plots, type of crop, names, and contacts of the related farmers: the parcel of farms.

This information is in principle available from the local Chamber of Agriculture. After various contacts and meetings, the Chamber of Agriculture of Seine et Marne was finally unable to clearly transmit all this information. In order to avoid any delay in the progress of operations, it was therefore decided to start permitting operations by asking each farmer about their potential contacts-fellow farmers.

In parallel, it was noted that another body could allow us to obtain the necessary database: the DRIAAF (Regional Directorate of Agriculture and Forestry). This body was contacted on 2022 May 2nd. Given

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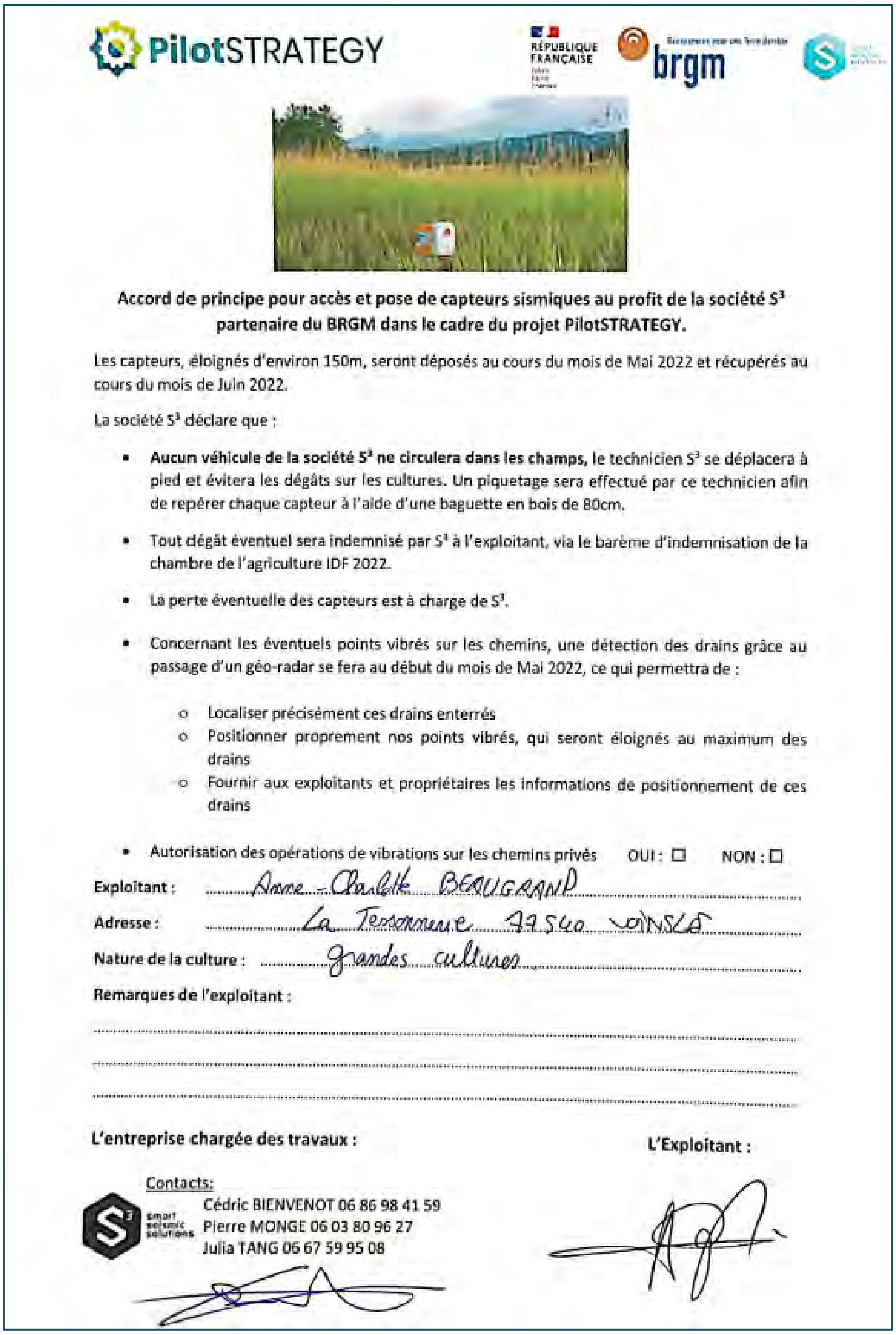
the semi-state status of the BRGM, we were able to obtain information with a sufficient level of confidentiality on May 4th.

The 'permitting' operations, or application for approvals of passages, started on April 11 and ended on May 10. Two people were responsible for the requests, while 2 distributed the project information flyers in all mailboxes of all the villages affected by the project. Nearly 10,000 flyers were distributed.



PilotSTRATEGY

Accord de principe pour accès et pose de capteurs sismiques au profit de la société S³ partenaire du BRGM dans le cadre du projet PilotSTRATEGY.

Les capteurs, éloignés d'environ 150m, seront déposés au cours du mois de Mai 2022 et récupérés au cours du mois de Juin 2022.

La société S³ déclare que :

- **Aucun véhicule de la société S³ ne circulera dans les champs,** le technicien S³ se déplacera à pied et évitera les dégâts sur les cultures. Un piquetage sera effectué par ce technicien afin de repérer chaque capteur à l'aide d'une baguette en bois de 80cm.
- Tout dégât éventuel sera indemnisé par S³ à l'exploitant, via le barème d'indemnisation de la chambre de l'agriculture IDF 2022.
- La perte éventuelle des capteurs est à charge de S³.
- Concernant les éventuels points vibrés sur les chemins, une détection des drains grâce au passage d'un géo-radar se fera au début du mois de Mai 2022, ce qui permettra de :
  - Localiser précisément ces drains enterrés
  - Positionner proprement nos points vibrés, qui seront éloignés au maximum des drains
  - Fournir aux exploitants et propriétaires les informations de positionnement de ces drains
- Autorisation des opérations de vibrations sur les chemins privés OUI : ☐ NON : ☐

Exploitant : Anne-Charlotte BEAUGRAND

Adresse : La Terronnerie 77540 VOINSLE

Nature de la culture : grandes cultures

Remarques de l'exploitant :

....

....

....

L'entreprise chargée des travaux : **L'Exploitant :**

Contacts:

Cédric BIENVENOT 06 86 98 41 59

Pierre MONGE 06 03 80 96 27

Julia TANG 06 67 59 95 08

Figure 5-7: Example of a passage agreement signed by the operator

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Liberté Égalité Fraternité

Géosciences pour une Terre durable
brgm

smart seismic solutions

CAMPAGNE DE MESURES GEOPHYSIQUES

10 Mai au 30 Juin 2022

PilotSTRATEGY

POURQUOI ?

Le BRGM (Bureau de Recheches Géologiques et Minières) et S³ souhaitent **étudier le sous-sol du bassin parisien** dans le cadre d'un projet de **recherche** sur le stockage géologique du CO_2. Ces stockages pourront jouer un rôle important pour la **transition énergétique** et la **lutte contre le dérèglement climatique**.

COMMENT ?

La méthode utilisée (sismique réflexion) est non-invasive. Elle consiste à réaliser **une image du sous-sol** en générant des **ondes acoustiques** à l'aide de camions vibrateurs, comme une échographie à grande échelle.
Ces vibrations, de très faible amplitude, se propagent dans le sous-sol et se réfléchissent lorsqu'un changement de couche géologique est rencontré. Ces réflexions remontent vers la surface et sont enregistrées à l'aide de petit capteurs sismiques sans fil (géophones).
Les géophysiciens reconstituent ensuite une image du sous-sol en profondeur à partir de l'analyse des signaux enregistrés, et des connaissances géologiques de la zone.

OU ?

La Campagne se déroulera principalement sur la Communauté de Commune de la Brie Nangisienne, mais également en partie sur celles du Val Briard et de Brie des Rivières et Châteaux.
Les capteurs seront disposés tous les 150m sur une grille Nord / Sud. Les Points vibrés seront réalisés en très grande majorité **sur les routes et chemins du domaine public**.

NOUS AVONS BESOIN DE VOUS

La bonne qualité des données acquises pour cette étude est importante pour notre futur à tous. **Il est très important que les capteurs ne soient pas déplacés.**

N'hesitez pas à nous écrire !
contact@s3seismic.com

SMART SEISMIC SOLUTIONS SAS - Capital 101,410 EUR - RCS Paris 849 313 937 www.s3seismic.com

Figure 5-8: Flyer distributed

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In total, 84 farmers were contacted, 63 gave us permission to position our sensors in their plots and 16 farmers refused our passage despite various interventions, including serious support from the BRGM.

The 16 farmers who refused passage in their plots represent about 20% of the total area of the project. Nevertheless, we were able to position our sensors on the public domain between their plots which limited the loss of geophysical data.

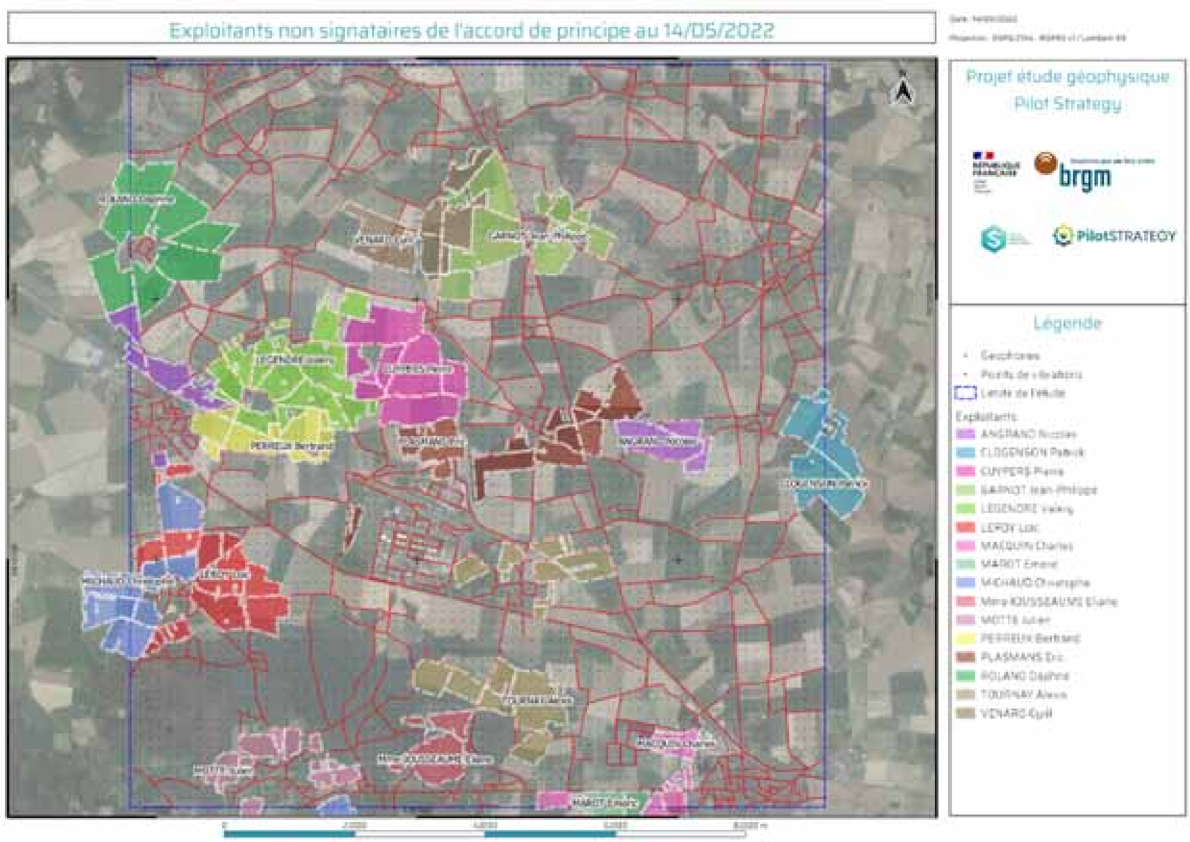

Figure 5-9: Farmers refusal location map

In order to be able to circulate and operate with vibrator trucks on the entire public network (paths, communal roads and departmental roads), requests for municipal and departmental by-laws have been made. Only the city of Nangis refused our passage on June 10th. The official request was made on April 13.

The PilotSTRATEGY project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101022664

Nangis, le 09 juin 2022

Direction des Services Techniques
Affaire suivie par Mickael YANG

Tel : 01.64.60.52.04
st.direction@mairie-nangis.fr

SMART SEISMIC SOLUTIONS
A l'attention de M. WALLENDORF
24 rue Louis Blanc
75 010 PARIS

N/Réf. : 2022/ST/MK/NLB/43329
Lettre recommandée avec accusé de réception n° 1A 187 031 2706 1

Objet : Refus d'autorisation concernant le passage d'un camion vibrateur sur la collectivité

Monsieur,

Ce courrier fait suite à votre demande d'autorisation de passage d'un camion vibreur sur la collectivité.

Je suis au regret de vous informer qu'après avoir pris des renseignements concernant vos procédés techniques et les potentielles nuisances engendrées auprès d'autres collectivités, nous ne donnerons pas de suite favorable.

De plus, nous sommes étonnés que vous ayez disposés des capteurs avant même notre autorisation. Aussi, je vous demande de retirer tous vos capteurs qui ont été posées, sans accord au préalable, sous un délai de 3 jours.

Restant à votre disposition pour tout renseignement que vous jugeriez utile, veuillez agréer, Monsieur, mes sincères salutations.

Nolwenn Le BOUTER

Le Maire

Figure 5-10: Nangis' rejection letter

Communication upstream of the project might have convinced municipalities and large landowners recalcitrant to the project. This communication could have been undertaken at a high level, for example between the BRGM and the Ministry of the Environment.

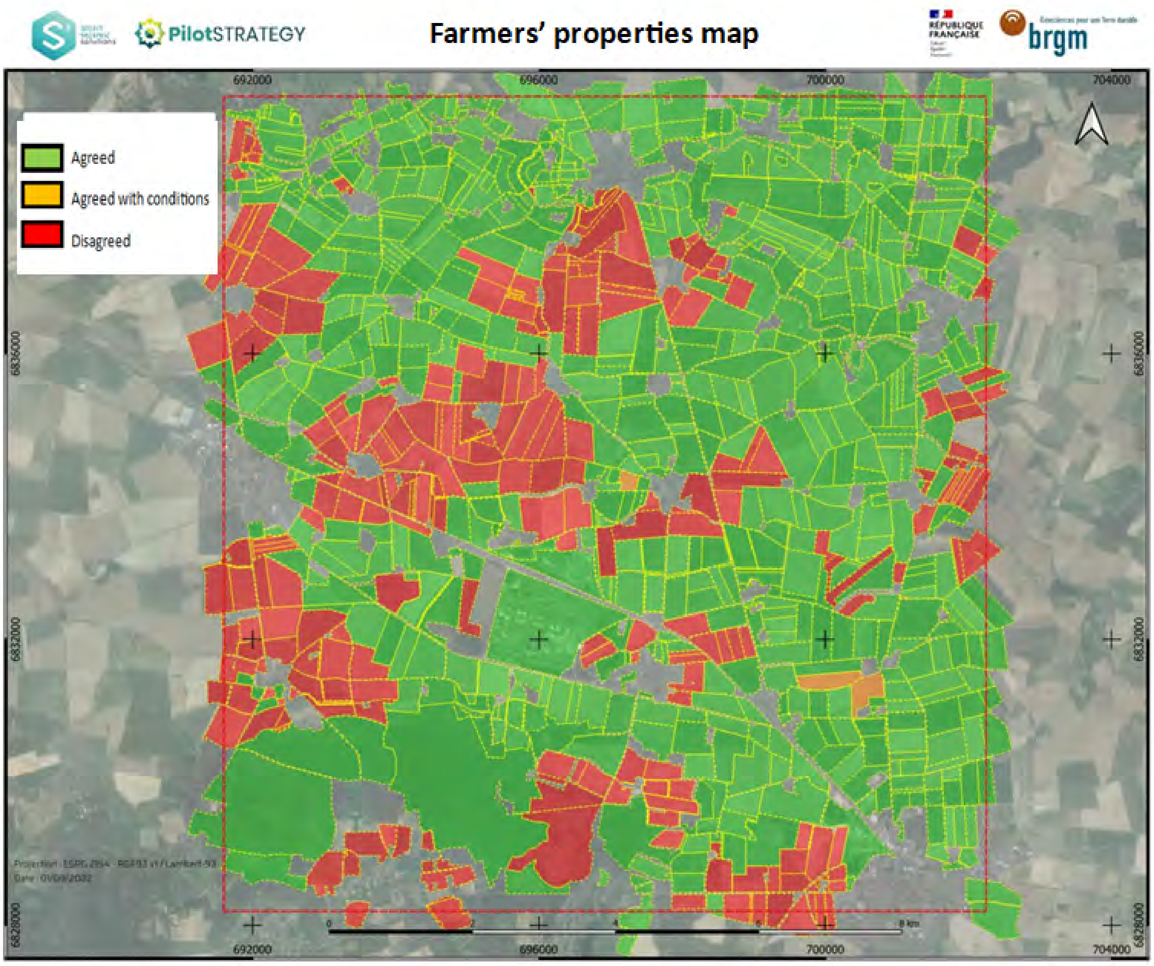

Figure 5-11: Status of permitting at the end of the project

Using the schedule of sensor deployment operations, we contacted each operator to inform them of our imminent passage. This close communication was appreciated.

We identified only 2 cases of crop damage. One concerns a plot of barley, the other beets. Operators were systematically warned of the damage that could be caused (very minor) and the compensation process that we would put in place at the end of the project. This process has been well followed, the farmers have been compensated for their loss.

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Figure 5-12: Crops damaged during seismic operation

At the end of the project all the operators who collaborated were contacted to thank them for their participation, a bottle of champagne was distributed to each.

Figure 5-13: Thanks from a farmer

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6. Operations

6.1. Topography

6.1.1. Scouting

No major difficulties concerning the implantation of traces or VPs (Position to Vibrate). Only the crossing of the forest will be a little more difficult because there is little access and some paths are narrow and very wet. The first reconnaissance was made at the beginning of March, a period when the trees do not yet have foliage. The absence of foliage allowed us to lift all paths to GPS in RTK mode (real time kinematics). A Trimble R12 receiver was installed on a Toyota Hilux vehicle.

More than 300 km of roads, paths and accesses were surveyed in RTK mode. The data was transmitted to the QC level to validate the theoretical positions of the vibrators when they are in production. Initially it is planned to make 30000 Vibrated Points and install 5000 sensors

The month of March was favourable to carry out the reconnaissance because with the absence of foliage the paths in the forest could be lifted in RTK mode.

Figure 6-1: GPS favorable area on the left and Losing GPS signal area on the right

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6.1.2. Implementation

Satellite imagery

We used the parcel databases, Topo road network of the IGN, and the various Rasters, such as Google Road, Google Satellite, open StreetMap to plan the implantation of the Vibrated Points and the Receivers.

The Geoportals website provides access to the parcel register, which facilitates the delimitation of "NO GO" zones. Access prohibited or subject to some restrictions

Locus Map (mobile outdoor navigation app) was used for location in the field.

Digital terrain model

For the Seine et Marne department, a digital terrain model (DTM) with an accuracy of 1 m is available on the Géoportails website.

The digital model is used to correct elevation anomalies when GPS does not use corrections or if it is in natural mode.

6.1.3. Equipment

GPS Rtk Radio

The main positioning method is RTK GPS, in UHF radio mode and possibility to switch to GSM mode (Global System for Mobile communication) on the European RTK Premium network.

Equipment used: Trimble R9s, R10 and SPS855 for vibrator trucks.

A differential station was set up to transmit the corrections via a radio signal. This station was installed on the farm so that it could intervene quickly in the event of a breakdown. The addition of a UPS connected to the electrical network eliminates battery problems (UPS for Uninterruptible Power Supply, this is a device that allows a computer to keep running for at least a short time when incoming power is interrupted).

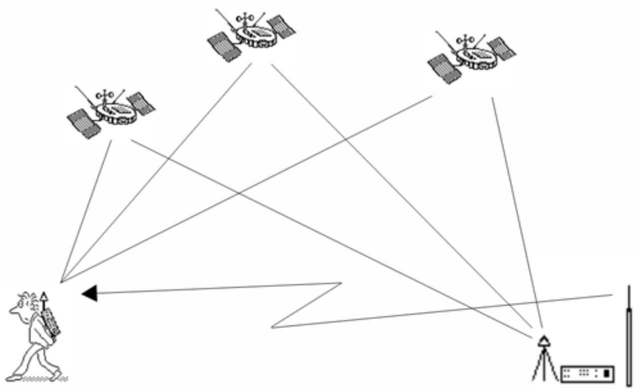

Figure 6-2: RTK correction via radio signal

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GPS RTK Via GSM

It should also be noted that all our GPS RTK had in addition the possibility of receiving GPS corrections by GSM signal via SIM cards with an RTK-PREMIUM subscription. When we were not able to receive real-time corrections from the differential basis, we had the opportunity to receive corrections.

Hardware used: Trimble R9s, R10 with RTK Premium service.

The Trimble R12 was set up mainly for the drill on paths and clearings.

Inertial unit

Apart from the Trimble R12, it is virtually impossible to use GPS under dense vegetation. S³ has therefore acquired 2 ZUPT inertial units. With the Trimble R12 Receiver, we have previously installed 150 points for starting and setting the inertial units. In wooded areas all the routes of the vibrator trucks have been materialized thanks to these ZUPT with paint marks and implantation of bamboo stakes since the GPS vibrators do not work under plant cover either.

Field Teams

A chief surveyor supervised the teams and controlled the quality of the data acquired.

Eight versatile teams consisting of an operator and an assistant were mobilized to directly position the Rau or Wings (Acquisition System). A special 'Inertial' team managed the implementation of the points in the forest.

The field staff is also equipped with smartphones with navigation applications to easily go to workplaces (Waze, WhatsApp, Google Map etc. ...) and provide live information (Technical problems, or problem of authorization to enter the properties.

The data is in kmz format compatible with most GPS equipment.


Figure 6-3: Differential GPS Station (on the left) and Inertial station ZUPT (on the right)

Figure 6-4: Receiver Trimble R9s (on the left) and Field notebook with Trimble R10 (on the right)

Office equipment

A laptop PC to process the data, establish a QC on the implanted points, including GPS and inertial data processing software (GPSeismic) and *Qgis, Global Mapper and Locus* mapping software

6.1.4. Survey methodology

Verification of geodesy

Before starting the implementation and survey of the points, we must check if the measurements from our GPS receivers are homogeneous with the national network. For this it is imperative to find geodetic landmarks validated by the IGN (National French Geographic Institute).

On our work area, there were several geodetic points but many of them have disappeared. Only one point in the enclosure of a water tower remained intact. This is the point *GrandPuits-Bailly-Carrois II*

RTK Premium		Contrôle RTK sur Point IGN GrandPuits-Bailly-CarroisII II				Trimble R9s	
Station_Text	WGS84_Latitude	WGS84_Longitude	Local_Easting	Local_Northing	WGS84_H	Local_h	Geoid_N
Bailly-Carrois II	48.58113496	2.982993987	698745.609	6831213.761	170.047	125.809	44.239
Bailly-Carrois II	48.58113495	2.982994023	698745.612	6831213.760	170.044	125.806	44.239
Bailly-Carrois II	48.58113496	2.982993985	698745.609	6831213.761	170.044	125.805	44.239
Bailly-Carrois II	48.58113495	2.982994046	698745.614	6831213.760	170.052	125.813	44.239
Bailly-Carrois II	48.58113498	2.982994001	698745.610	6831213.763	170.047	125.808	44.239
		Standard Dev	0.002	0.001	0.003	0.003	
	RTK Premium S^3	Moyenne	698745.611	6831213.761	170.047	125.808	
	IGN	IAG GRS 1980	698745.600	6831213.850	170.030	125.772	
	Delta		0.011	-0.089	0.017	0.036	

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There is a small difference between RTK measurements and IGN values.

The corrections are therefore compatible with the values provided by the IGN (National French Geographic Institute)

Département : SEINE-ET-MARNE (77)
Commune : GRANDPUITS-BAILLY-CARROIS
Lieu-dit :

No du Site 7721102
Site du Réseau de détail

Azimut de la prise de vue : 307 gr

Carte : 2516 NANGIS

Point a

Borne IGN
Point vu en place en 2005

Azimut de la prise de vue : 193 gr

Système : RGF93 (ETRS89) - Ellipsoïde : IAG GRS 1980

Point	Longitude (dms)	Latitude (dms)	Hauteur (m)	Précision
a	2° 58' 58.7779" E	48° 34' 52.0887" N	170.03	< 10 cm
b	2° 58' 58.4420" E	48° 34' 52.5026" N	203.16	< 10 cm
c	2° 58' 58.4444" E	48° 34' 52.5032" N	203.16	< 10 cm

Système : RGF93 (ETRS89) - Projection : LAMBERT-93
Système altimétrique :NGF-IGN 1969

Point	e (m)	n (m)	Précision plani	Altitude (m)	Précision alti
a	698745.60	6831213.85	< 10 cm	125.772	< 1 cm
b	698738.72	6831226.63	< 10 cm	158.904	< 1 cm
c	698738.77	6831226.65	< 10 cm	158.904	< 1 cm

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Checking GPS equipment

Next to the farm, we have established two checkpoints. One point for the differential station and another point for the daily control of GPS receivers before the teams leave for the field. Each operator parks the checkpoint, makes measurements and then compares whether the coordinates are identical with the known point. Errors may be due to a bad antenna height on the mobile or a coordinate error during a restart of the differential station.

6.1.5. Receivers deployment

All receiver positions are implanted and lifted. The operator guides himself with his field book or with a Smartphone in which all the points of the study are integrated. When the target is reached, the operator records the position of the point and the sensor number. The point can only be recorded in RTK Fix mode. The assistant makes a mark on the ground with a can of paint or a pennant if the terrain lends itself to it. The point number will be inscribed on the pennant. In case the target point is not accessible, the operator has the possibility to move the point while respecting a perpendicular offset from its initial position. Upon return from the field, the data is transferred to a PC and verified with *the GPSeismic* software. It is thus possible to check graphically if the offsets are well carried out and make the quality controls on the method of surveying.

Figure 6-5: Receivers deployment with Trimble R12

6.1.6. Sources deployment

During the reconnaissance, a continuous RTK survey was carried out on all roads and accesses corresponding to the source lines in order to prepare the course of the vibrators. The QC echelon will thus be able to precisely position all the Vibrated Points and add more if necessary. In the plain, the Source positions are not materialized, the vibrators are positioned in RTK mode via a guidance tablet located in the cabin of the vehicle. Some GPS reception difficulties in wooded areas because of the signals that bounce off the trees and generate multi trips. It will therefore be necessary to materialize all the VPs and the driver will settle on the landmarks. One topography survey crew has been responsible to re-implant the “poor quality points” (low precision coordinates).

Figure 6-6: High density forest area without any GPS coverage

6.1.7. Vibrators positioning

The vibrators will use the same GPS network and differential station as the topo echelon. A differential correction repeater is sometimes required.

The vibrators are equipped with a TRIMBLE GPS receiver model SPS855 and an internal radio to receive corrections. Once the VP is done, the next VP is displayed. The driver goes from target to target. On the tablet we put the basemap and accesses.

GPS Antenna measurements

The GPS antenna of the vibrator is located vertically from the vibrating plate. Its height is 3.48 m above the ground for the M26 and 3.15 m for the Prakla vibrator.

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Figure 6-7: Vibrateur M26 (on the left) and Vibrateur Prakla (on the right)

Vibrators positioning test

Before starting the acquisition, the vibrator is positioned on a control point (Point made in RTK by the topo echelon).

Trimble SPS855 receiver used in Vibrator trucks.

VIB1 = Point CHK sur la ferme

Point	Lat WGS84	Long WGS84	Ellipsoid Height	Easting RGF93	Northing RGF93	Alti MSL
Vib1	48°35'44.854558" N	2°59'13.577360" E	173.40	699049.10	6832843.22	129.18
Vib1	48°35'44.854606" N	2°59'13.578105" E	173.40	699049.11	6832843.22	129.18
Vib1	48°35'44.855070" N	2°59'13.578108" E	173.40	699049.11	6832843.24	129.18
Vib1	48°35'44.855126" N	2°59'13.577593" E	173.40	699049.10	6832843.24	129.18

VIB1	48° 35' 44.85500" N	02° 59' 13.57798" E	173.40	699049.11	6832843.23	129.18

QC vibrator positioning

The positions of the vibrators are recorded at the end of the vibration time as NMEA messages. We will use the GPGGA frame in which we will find the positions expressed in Latitude / Longitude / Ellipsoidal height in the datum WGS84.

Example GPGGA file :

$GPGGA,193443.00,4609.31563989,N,00604.83445855,E,5,14,0.8,419.234,M,49.653,M,2.0,1626*

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$GPGGA,193558.00,4609.31799080,N,00604.83800584,E,5,15,0.7,419.115,M,49.653,M,2.0,1626*4

$GPGGA,193721.00,4609.31983103,N,00604.84125621,E,5,14,0.8,419.043,M,49.653,M,2.0,1626*

$GPGGA,193828.00,4609.32217114,N,00604.84514382,E,5,14,0.8,418.951,M,49.653,M,2.0,1626*

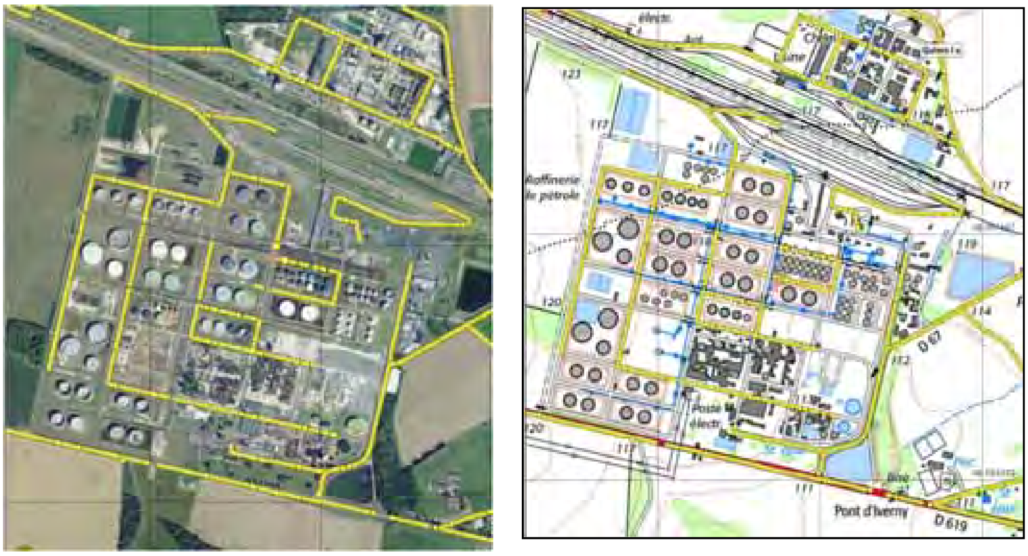

Figure 6-8: Positioning of Vibrators in a safety area.

The RTK positioning of vibrators is analysed by the QC department. In the event of a loss of signal, the vibrator truck assistant will mark the ground so that a topo operator can be sent to resume the unrecorded position.

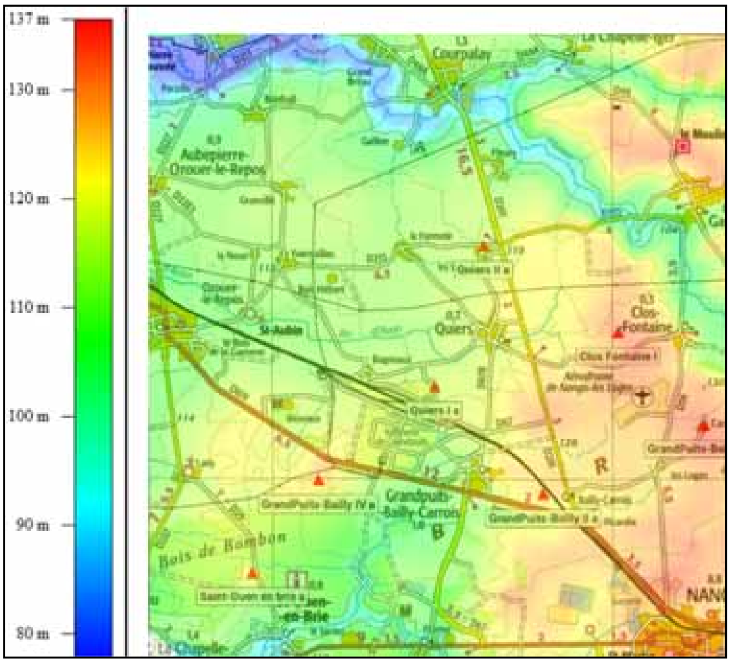

Figure 6-9: Elevation variations on the studied area

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6.1.8. Altitude correction

Trimble receivers use the global Geoid model which is EGM96. The French Geoid model is the RAF09, there is a difference between these 2 models. It is not possible to change the Geoid model in Trimble SPS855 receivers. It will therefore be necessary to make a correction on the MSL elevations. The routes have been lifted beforehand during the "scouting", so we can compare the elevations from the vibrators and the RTK survey. The measurements made by the GPS receiver of the vibrator are subject to the same specifications as the topographic measurements in terms of measurement qualities (RTK mode fixed, Numbers of satellites, Pdop level specifying the error propagation as a mathematical effect of navigation satellite geometry on positional measurement precision, loss of initializations or defects of corrections).

6.1.9. Geodesy parameters

GEODETIC PARAMETERS DEFINITION			
Pays	France	Projet	PilotStrategy
LOCAL DATUM		NAME	RGF93
	ELLIPSOID	Name	GRS 1980
		Semi-major axis	6378137.0
		Inverse flattening	298.257222101
	PROJECTION	Map Projection	Lambert 93
		Projection Type	Lambert Conform Conic
		Grid Zone (if any)	
Standard Parallels		Central Meridian	3°' East
L1 49°00'00 ''		Latitude of Origin	46°30' North
L2 44°00'00''		False Easting	700000
(For 2 parallel Lambert only)		False Northing	6600000
		Scale Factor at Origin	1
VERTICAL DATUM		Name	RAF09
		Units of Measurements	Mean Sea Level
		Geoidal Model	Meters
		Constant (correction)	0

DATUM SHIFT local to WGS84

3 Parameters Molodenski		
Dx =	0	m
Dy =	0	m
Dz =	+0	m

or

7 Parameters		
Dx =		m
Dy =		m
Dz =		m
Rx =		sec
Ry =		sec
Rz =		sec
Scale corr. =		ppm

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CHECK POINT(S) FOR THE NETWORK IN LOCAL AND WGS84 COORDINATES			
WGS 84	DATUM		RGF93
Bailly Carrois II	POINT NAME		Bailly Carrois II
48º 34' 52.0887" N	WGS 84 Latitude	Northing	6831213.85
02° 58’ 58.7749’’ E	WGS 84 Longitude	Easting	698745.60
170.03	WGS 84 Height	Local Height	125.772
	Geoid height		44.258

6.2. Sensors

Two types *of "node*" type sensors were used: Wing and RAU (Recording Acquisition Unit) both from Sercel.

500 Wings and 6000 RAUs were mobilized on the mission. Thanks to their one-month autonomy, the WINGs were primarily deployed in forestry, industry and urban areas when no grassy area could be found.

Note that there were no battery problems during the project.

- A specific deployment sequence has been put in place to ensure:
- The correct configuration of the nodes deployed (Tilt alert level, operating time range, sampling rate, ...). A test instrument was practiced every morning at 07:45 by each box.
- Turn on at deployment, turn off on recovery
- Recovery of QC statuses
- Data download and battery charging (RAUs only).

All sensors were installed before the start of the acquisition operations.

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The six deployment teams consisted of one driver and two operators. A supervisor (Line Boss) organized the program and the field teams.

In order to minimize any damage to crops, it was decided to make maximum use of rollovers (tractor running areas) in the fields. The sensors that could not be moved to the roadside were therefore deployed on these tracks. Efficiency and installation time were affected, but the lack of crop damage avoided compensated for this 'heavier' logistics.

A start-up meeting specific to deployment operations was also held to focus particularly on this issue of minimizing our impact on crops.

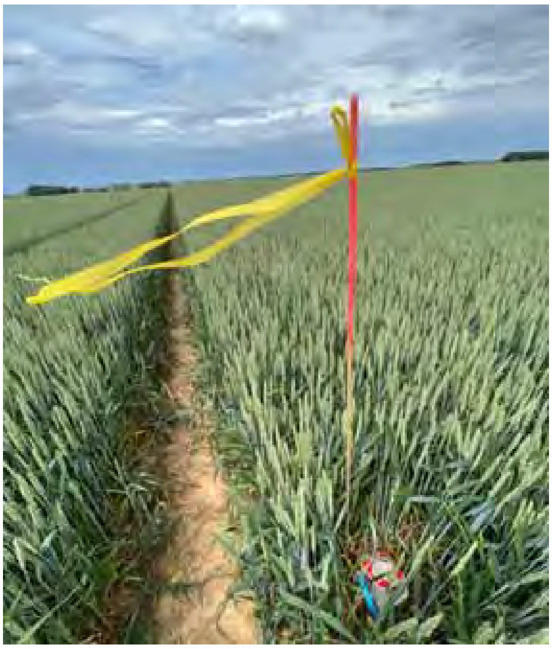

Figure 6-10: Deployment of receivers in a crop field

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Figure 6-11: Kick off meeting of field team

The deploying and pick-up crews were leaving the hotel after the 6:45 a.m. morning security meeting.

In order to support the communication campaign and answer potential questions from local residents, flyers explaining the campaign were attached to sensors in urban areas.

Figure 6-12: Urban installation of a sensor with explanatory flyer

A total of 4451 RAUs and 491 WINGs were deployed in 12 days.

In order to compensate for the 12 days of operation of the RAUs, a sensor change plan (*swapping*) was put in place from the start of the acquisition. 10% of the fleet had to be recovered every day to ensure that all the UARs would be recharged in battery and data downloaded. A total of 4378 sensors have been changed, 100% of the fleet has been recovered.

The final recovery of all sensors took 10 days.

We indexed the receivers that were moved for various reasons (harvesting, change of type of sensors...). A total of 11 Sensors were indexed only.

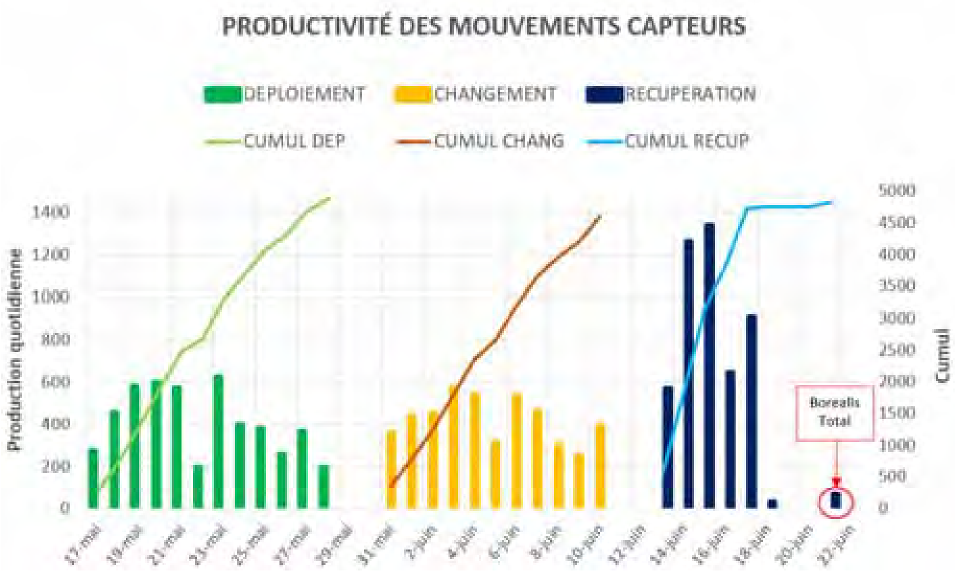

Figure 6-13: Chart of sensors productivity in terms of deployment, changing and pick-up

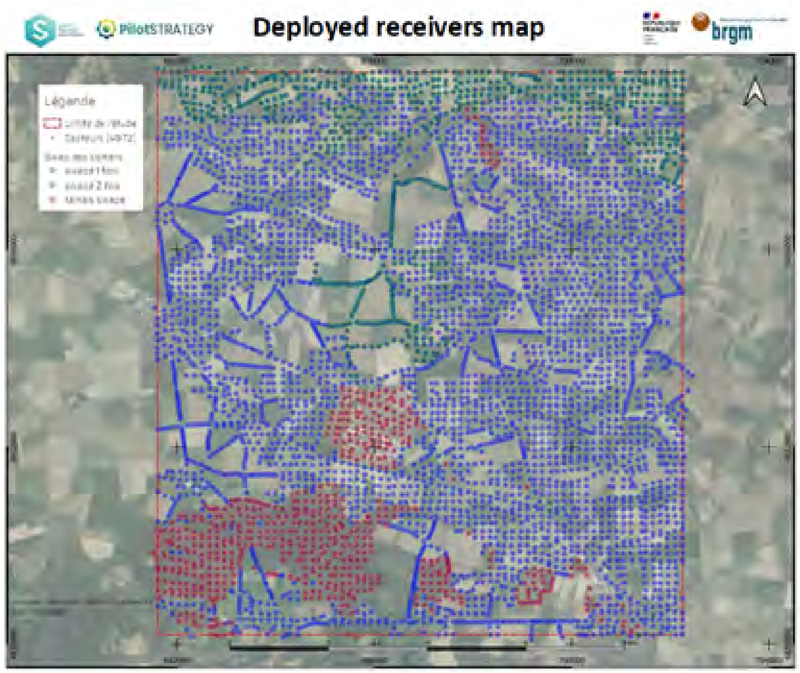

Figure 6-14: Map of sensors (receivers) deployed

A total of 3724 RCVs were swapped 1 time, 654 RCVs were swapped 2 times. 794 RCVs were never swapped including 491 WINGs. Other deployed UARs that have never been swapped are UARs deployed after the start of the acquisition with sufficient battery levels to complete the acquisition.

6.2.1. WING sensor

The Sercel WING integrated node system offered a lot of flexibility in a "challenging" environment. Its size, its load capacity and to quickly transmit its QC statuses, considerably optimizes the operations in quality and speed of execution.

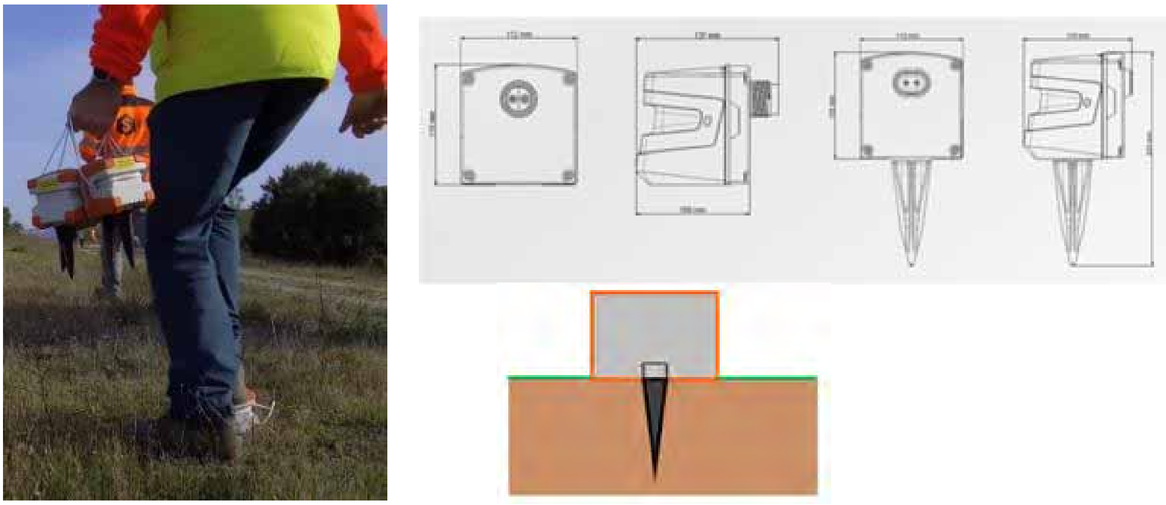

Figure 6-15: Dimensions and Implantation of the WINGs

6.2.1. RAU sensor

The RAUs were coupled to Sercel SG5 geophones.

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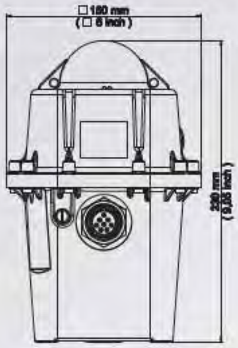
UNITE Specifications

	RAU *eX*	RAU *eX-3*
GENERAL		
Number of channels	1	3
Timing accuracy	better than 20 µs	better than 20 µs
Memory autonomy (2 ms sampling)	480 h	310 h
Internal battery autonomy (Autonomous mode)	140 h	130 h
External battery autonomy (12 V/15 Ah, Autonomous mode)	250 h	270 h
External battery input	11 V - 18 V	11 V - 18 V
WEIGHT		
Internal battery included	1.6 kg	1.95 kg
ENVIRONMENTAL LIMITS		
Operational temperature	-40 °C* / +60°C	
Storage temperature	-40 °C* / +60°C	
Humidity	IP68	
Internal battery charge temperature	0°C/+40°C	
RADIO TRANSMISSION		
WLAN Frequency	2.4 - 2.4835 GHz	
Power	18 dBm	
Antenna	Omni-directional patch	
Data rate	Up to 11 Mbps	
Range	Up to 1500 m (LOS)	
GPS		
Frequency	L1 (1575.42 MHz)	
Cold start acquisition sensitivity	173 dBW	
TTFF (cold start)	< 30 s (sat. signal strength = -130 dBm)	

	RAU *eX*	RAU *eX-3*
UNITE TESTS		
Battery status	✓	✓
GPS status	✓	✓
WLAN signal strength	✓	✓
SENSOR TESTS		
Resistance	✓	✓
Tilt	✓	✓
Leakage	✓	✓
Noise	✓	✓
Crosstalk		✓
INSTRUMENT TESTS		
Distortion	✓	✓
Gain	✓	✓
Phase	✓	✓
Noise	✓	✓
Crosstalk		✓

Note: Sercel reserves the right to change its specifications without prior notice.



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6000 Geophones Sercel SG5 have been mobilized and tested :

Figure 6-16: Sercel geophones

At 22°C	SG-5	SG-10HS
Natural frequency	5Hz ± 7.5%	10 Hz (± 3.5%)
Distortion	≤0.1%	
Sensitivity	80 V/m/s± 5%	85.8 V/m/s (± 3.5%)
Operating Temperature	-40°C to +80°C	

Specifications subject to change without notice

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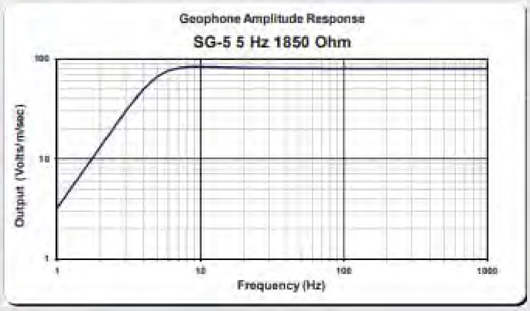
HIGH-SENSITIVITY GEOPHONES SENSORS SG-5	
Natural Frequency (± 7,5 %)	5 Hz
Coil Resistance (± 5 %)	1850 Ω
Pk-Pk Coil Travel	3 mm
Harmonic Distortion[1]	<0,1%
Sensitivity (± 5 %)	80 V/m/s
Open Circuit Damping (±7.5 %)	0,6
Moving Mass	22.7g
Spurious Resonance	> 150 Hz
Diameter	32 mm
Length	43 mm
Weight	170 g
Operating Temperature	-40° to 80°C

Except where otherwise noted all electromechanical specifications are valid at 22 °C and from 0 to 10 degree tilt.
(1) Measured at 12Hz and 0.7 in/s peak-peak velocity



3 Line Checkers have been set up to compensate for the deterioration of the *spread*. The major degradation lay in the *tilting* of the boxes (poor verticality of the sensor) and the displacement from their theoretical positions. These *line checkers* were dispatched throughout the study area in order to recover the missing statuses via their DH (Data Harvester) tablets.

Thanks to the DH tablets and walking near the sensors, the line checkers collected the QC statuses (about 100m radius):

- Battery level
- GPS signal quality
- GPS coordinates
- Instrument test result (from the latest BIT)
- String test result (of the latest BIT)

Figure 6-17: Tablet QC RAU (Data Harvester

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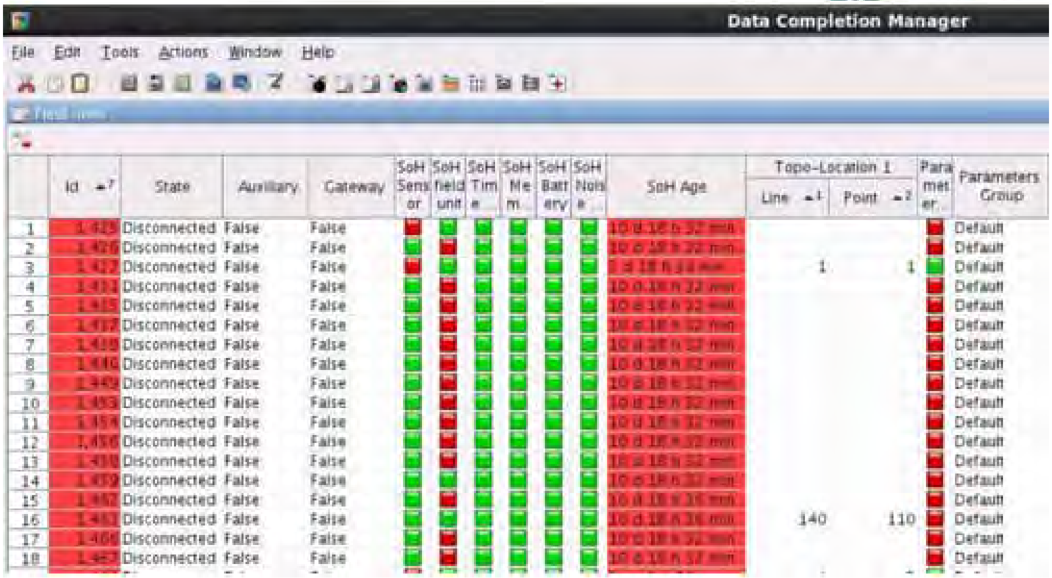

Figure 6-18: Exemple de liste status QC des RAUs

No act of deliberate vandalism was noted throughout the project, the little damage observed comes mainly from roadside mowing of municipal or departmental services, which in most cases paid attention to the sensors.

Degradation in the forest comes from wild boars turning the earth to feed.

Moved or broken sensors were systematically replaced to ensure data quality and coverage.

Figure 6-19: Destroyed sensors

The Sensor Workshop team takes care of the configuration, battery charging and downloading of sensor data, it consisted of a supervisor and 2 operators.

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6.3. Sources

A major step, for the smooth running of vibrations, is the recognition of the feasibility of pre-planning, source points (*Vibro path*). We have set up beforehand 1 team specially dedicated to this task including a Chief Topographer equipped with a TOYOTA HILUX 4x4 vehicle and a GETAC F110 tablet PC with the cartographic software "Cartolander" to record in ESRI Shape file format, via its integrated GPS, all the accesses to be used by the vibrator trucks. This work, which is essential, has made it possible to:

- Validate the different routes before the commitment of the vibrator trucks,
- Identify many difficult or inaccessible areas in order to define the type of vibrator
    - o Find, in collaboration with the QC department, an alternative positioning or invalidate a point in *SKIP* if no alternative is possible,

Vibrators quantity	**3 x M26** **3 x PRAKLA**
Vibration quantity per day per vibrator	360
Vibrator quantity per VP	1
Acquisition type	SRS (Simultaneous Random Sweep)
Sweep type	Random
Sweep frequency range	3-90 Hz
Sweep lenght	30 secondes
Drive level	80% (40 % in urban area)
DGPS (RTK)	Oui

Figure 6-20: PRAKLA truck sending vibration during a test

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The *Production* Supervisor and the QC department collaborated to create a production plan by vibrator type (map below). The use of Prakla, lighter and more agile, has been prioritized in urban and industrial environments.

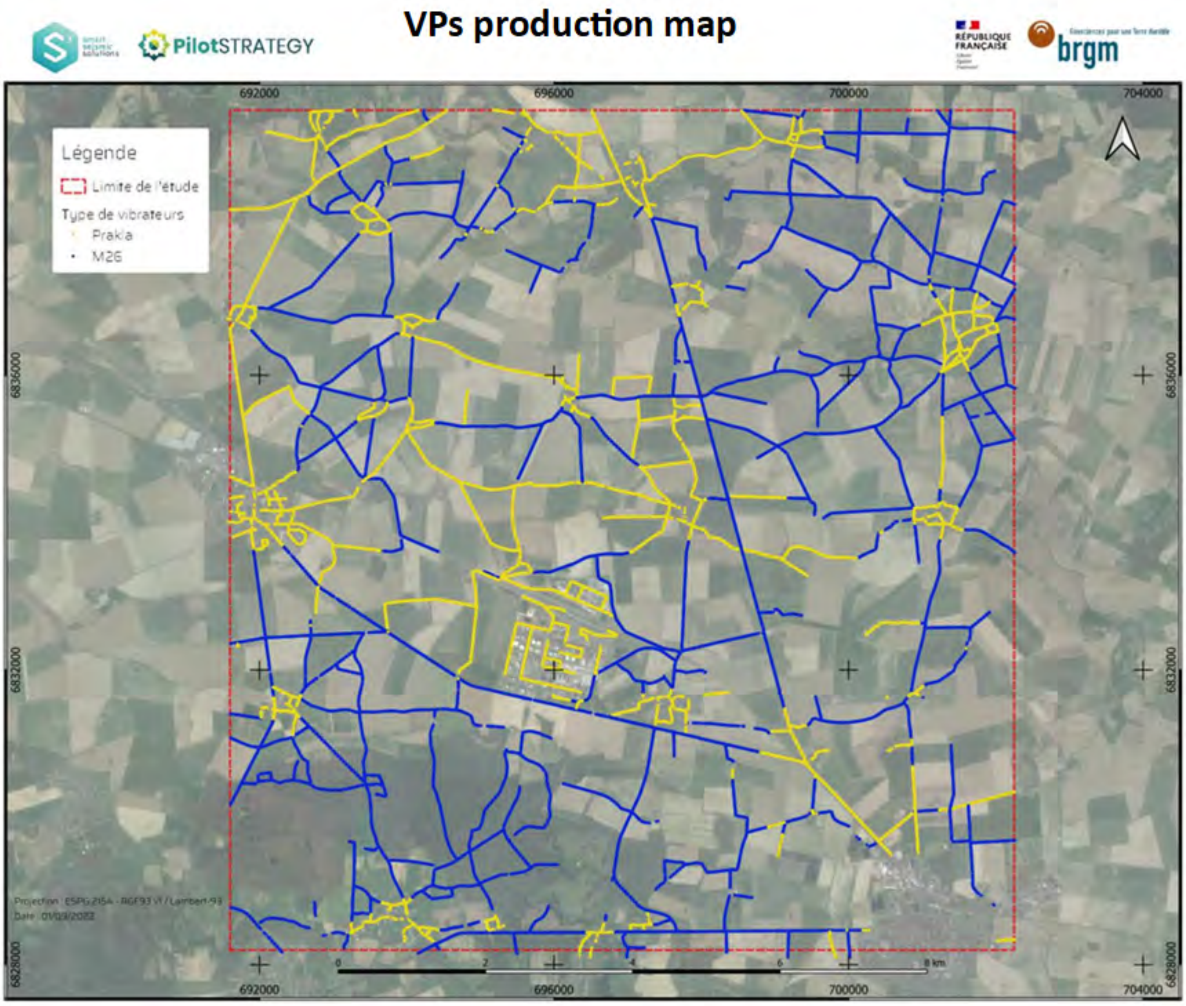

Figure 6-21: Final map of vibration points

The vibration operation started as planned on 2022 June 1st.

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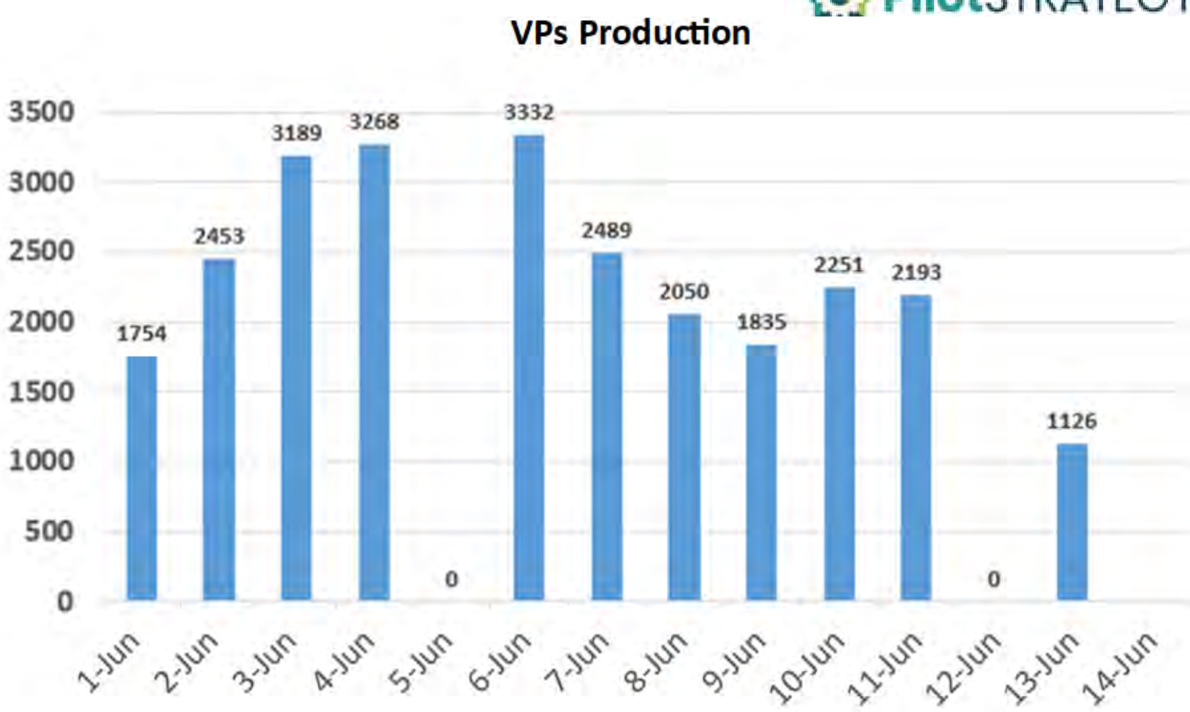

Figure 6-22: Productivity of vibration points by day

6.3.1. Vibrators

A total of 6 vibrator trucks of 2 different models were used on this project to meet all constraints (sensitive structures, manoeuvrability in urban areas, noise constraints, cultivated areas, etc.):

QTÉ	Vibrators Type	Peak Force	Width	Weight
3	Mertz M26	52,000lbs	2.5m	27t
3	PRAKLA	28,000lbs	2.5m	16t

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6.3.2. Prakla

This 16-ton vibrator, supplied by our partner Geotec SA, offers a very interesting versatility for a prospect containing both urban and agricultural areas. Able to move at nearly 60 km/h without escort. A noise reducer also significantly reduces noise pollution.

FLEET n. 1 VIBRATORS (CE Marked)	6 units
Manufacturer	**Prakla Geomechanik**
Model	VVCA/E
Peak Force	125 000 N
Piston Area	59.55 cm²
Mass Weight	4300 lbs
Driven Weight	135000 N
Usable Stroke	±35 mm
Frequency Limit	6 to 160Hz*
Length	7350 mm
Width (variable depending on tyres)	Up to 2650 mm // **2500 mm on the SIG project**
Height	3250 mm
Wheelbase	4100 mm
Turning Radius	6.75m
Speed (variable depending on tyre size)	Up tor 40 Km /h
Slope Capacity	60%
Weights	16 000 Kg
Hold -Down	28000 lbs
Base Plate	3500 lbs
Shape	4x4 Crab Tractor
Area	All terrain

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6.3.3. Mertz M26

This 26-ton vibrator is one of the heavy vibrators to maximize the energy injected into "non-sensitive" areas.

Following the requests of some farmers and the unfavourable humidity conditions on the paths of cultivated fields, it was decided to reduce as much as possible the use of these vibrators.

Model	M26HD/623B Seismic Vibrator
Length	10.5 m
Width	3.45 m
Height	3.8 m
Peak Force	276 kN
Piston Area	133.4 cm²
Mass Weight	
Driven Weight	Front axle : 15 000 kg Rear axle : 14 250 kg Hold down : 28 500 kg Gross : 29 250 kg
Frequency Limit	7 to 250 Hz
Usable Stroke	7.62 cm peak-peak
Speed Max	28.9 km/h
Slope capacity	60 %
Turn circle	20.5 m

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6.3.4. Fleet composition

Each vibrator fleet consisted of:

1. 1 vibrator operator
2. 1 vibrator navigator (called Vib Pusher or 'rabbit')
3. 1 or 2 operators PPV (Peak Particle Velocity)
4. 2 traffic controllers

In order to supervise these teams, a management made up of experienced staff was present during the entire production:

1. Manager Operations – Planning, launch/monitoring of operations, security, management of permitting issues
2. Field Manager – Management of mechanical and electronic failures
3. Observe – Management of the production of vibrated points

Figure 6-23: Management of road traffic during vibration operations

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6.3.5. Operational organization

The realization of the daily program of a vibrator depends a lot on the optimization of the route taken, as well as a good anticipation of problems of accessibility / permitting. For this purpose, several support documents were made available to the browser:

1. A phone used by the vib-pusher with:
    1. *Google Maps* **file** of the daily program allowing teams to use the application to know the shortest path between vibration zone
    2. The program's *Google Earth* **file** containing NO GO zones and exclusion buffers
    3. *Vibropath* **file** confirming accessible paths for vibrator trucks
    4. Permittage file describing all access points under special conditions

For its part, the vibrator operator had a tablet including:

1. All VPs (Position to Vibrate)
2. The set of exclusion *buffers* containing all sensitive NSOs

The smooth running of the acquisition depended on the navigator to guide the vibrator truck, then on the vibrator operator for the correct positioning of his truck (positioning provided by GPS precision RTK, the topo implantation before production having been made mainly in these urban areas or forests with GPS acquisition difficulties.

Permitting was one of the main challenges of this project, as often in this type of urban/rural project. Zones marked as '*NO GO*' specifying a ban on driving with vibrators were communicated and checked daily.

Refuelling was managed with Total Energie. The delivery was made on a tank of 6000 litres at the base. Then, a dedicated operator with a light vehicle (Toyota Hilux) equipped with a 1000-liter tank managed the refuelling for each vibrator according to need in situ.

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1.1.1.1 Vibrators parking

In order to make operations more agile and responsive in the morning, parking areas were identified and transmitted to vibrator teams throughout the project by permittage teams. Several car parks were therefore used on a daily basis.

Figure 6-24: Map of truck vibrators parking

Out of a total of 35395 theoretical VPs on the project:

1. 27215 VPs could be vibrated including 997 reshoots at the end of the project because there had been heavy rain one day.
2. 7183 VPs had to be *skippered* of which only 382 in production:

Most of the VP Skips were during the planning phase (preplan), largely because of the NO GO zones (refusal of owners to vibrate on their way) but also because of the refusal of the city of Nangis which resulted in the loss of 936 VPs.

The rest of the SKIP VPs were in the production phase (382 VPs) due to problems:

1. Access to fields related to the weather (ruts, soil compaction, sowing, etc.)
2. PPV value too high
3. Road too narrow

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Figure 6-25: 'skipt points' on the way to avoid too much damage

1.1.1.2 PPV MONITORING

During the preparation phase, a safety distance test was conducted by APAVE on 23 May with a vibrator of each type. It was this test that confirmed the safety distances and vibration limits to be respected in the study area.

The purpose of the PPV (Peak Particle Velocity) monitoring operations was to ensure that vibration limits remained non-destructive for any nearby structure. The threshold of 4 mm/s was retained: Threshold if between the limit standard of 'extremely sensitive' and 'sensitive' buildings.

Depending on the number of points and the production rate to be held, 1 or 2 operators were mobilized.

Figure 6-26: PPV operators

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1.1.1.3 STATUTS QC

The QC statuses from each sweep can be analyzed using AVQC software which allows to view the alerts and source errors from thresholds on the characteristics of the vibration (DGPS, Amplitude, Phase ...).

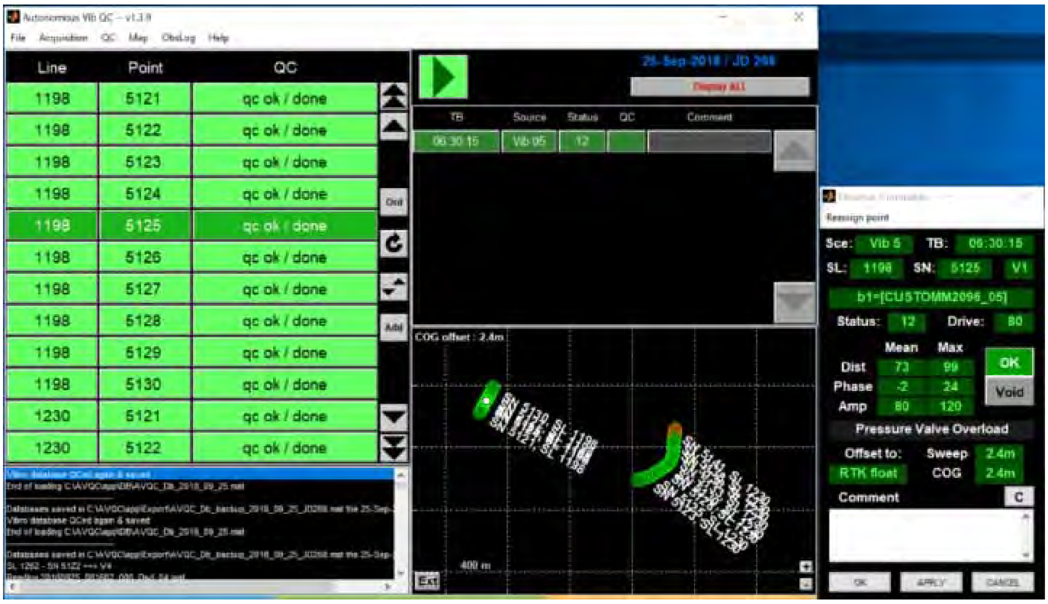

Figure 6-27: Vibrator tablet

A QC data base (VAPS) is generated and stored for each sweep by the DSD in real time. This data base includes attributes such as phase, distortion, and the signal coming from the plate and ground accelerometers of the vibrators also called *ground force*. The ground-force and the pilot are written in SEGD format on the guidance tablet PC and are sent daily to the QC department.

1.1.1.4 POSITIONNING

The vibrators have all been equipped with a TRIMBLE GNSS receiver, and an internal UHF radio modem and tablet PC for guidance and recording of vibration data.

The vibrators used the GPS/GNSS on board unit and guidance *software* to reach the source point. The true position is then directly recorded in the vibrator and transmitted to the recorder. The true vibrated positions are then analysed and checked before being transferred to the final SPS file.

The GPS antenna is centred above the vibration plate, and its height taken into account.

Dedicated base stations were used for the positioning of the vibrators. They consist of a GNSS receiver and a UHF radio transmitter located near the recorder, on a point belonging to the network of control points.

At the end of the *sweep*, the final position of the VP is measured and recorded in the tablet PC as well as in the SPS file generated by the recording unit. QCs are sent in real time to the base via UHF/GSM communications.

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In order to compensate for a possible radio 'mask' due to tall buildings, a redundant system was planned. This system for receiving GPS corrections by GSM network integrate SIM cards. 6 international Premium RTK subscriptions have been subscribed and 6 *SettopCell Xtrem Systems:* Reception GPS correction by GSM have been installed.

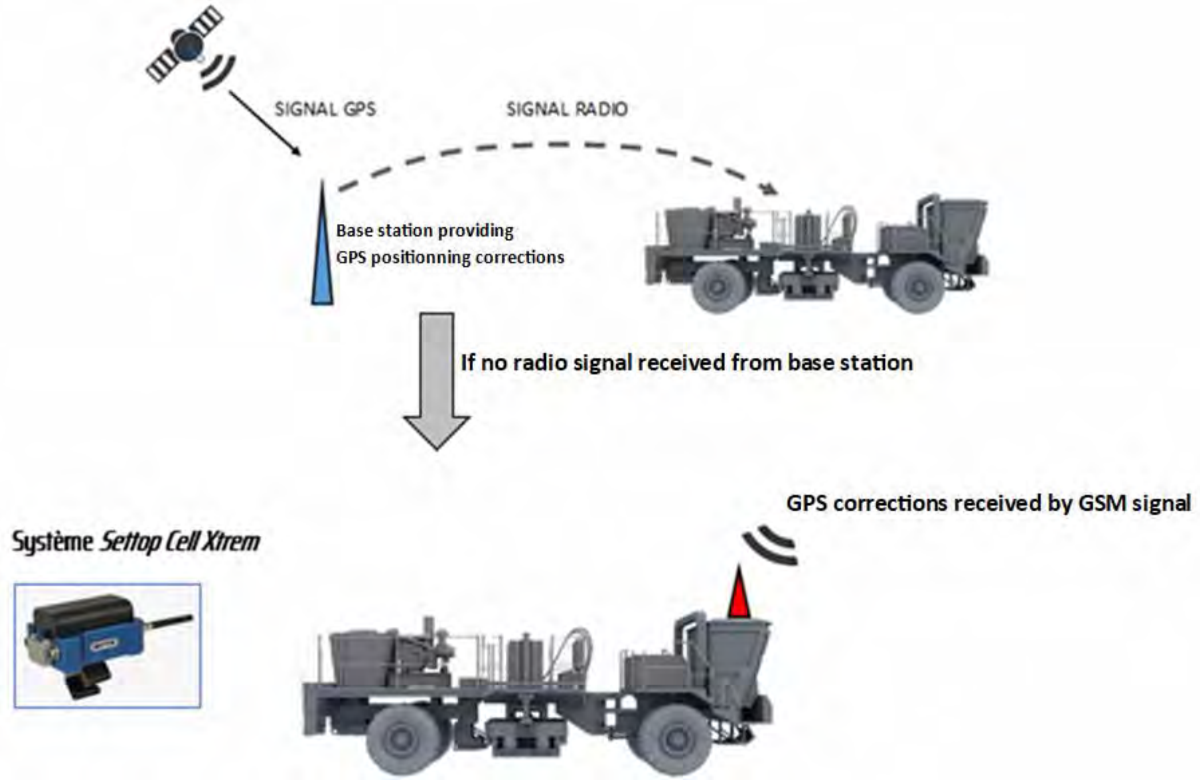

Figure 6-28: Principle Settop

In the densest urban and forest areas generating GPS masks, source points were marked and recorded via the inertial unit or the R12 receiver.

1.1.1.5 SIMULTANEOUS RANDOW SWEEP

Each vibrator produced a *random* sweep (3-90 Hz) with its own signature according to its mechanical constraints. This sweep has the same energy as a linear sweep with a lower Peak *Particle velocity level.* The signature will be used in the *deblending* process that will distinguish the data of each vibrator.

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1.1.1.6 SPECIAL AREAS (safety areas)

Several areas required preparatory work as well as special permitting treatment:

1. Total (refinery)
2. Borealis (fertilizer plant)

Each light vehicle or vibrator had to have obtained an entry permit

1. Obtaining entry permits
2. Passage of the Chemical Risk 1 training for the operators and 2 for the supervisor
3. Editing a risk assessment plan
4. Badge application procedure and security training
5. Special working hours and zoning had to be strictly adhered to

Figure 6-29: Intervention on Borealis

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Figure 6-30: RCV & VP TOTAL

Figure 6-31: RCV & VP Boréalis

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It should be noted that the sugar factory of Nangis Lesaffre and the golf course of Fontenailles refused the passage of vibrators. We were finally able in the last days of the acquisition to put sensors in the LESSAFRE factory.

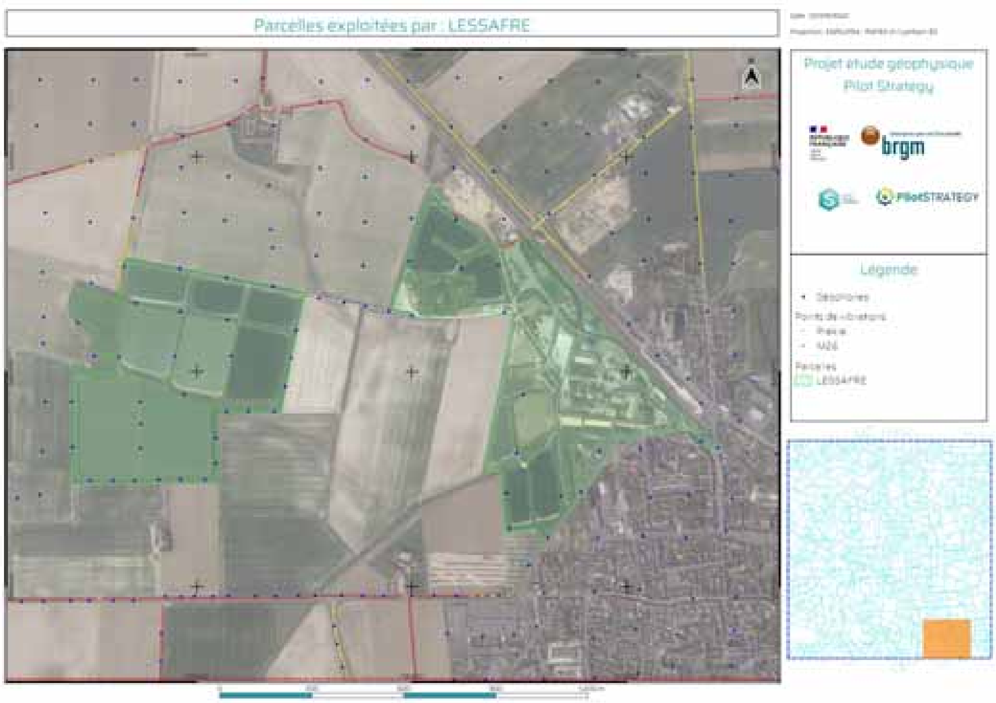

Figure 6-32: RCV factory LESSAFRE deployed on June 8

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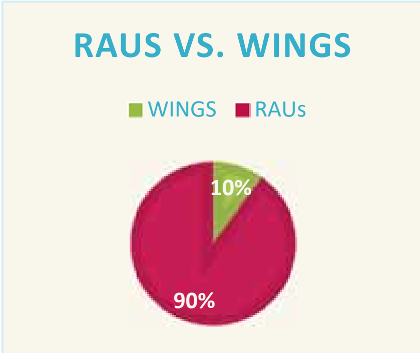
6.4. Production statistics

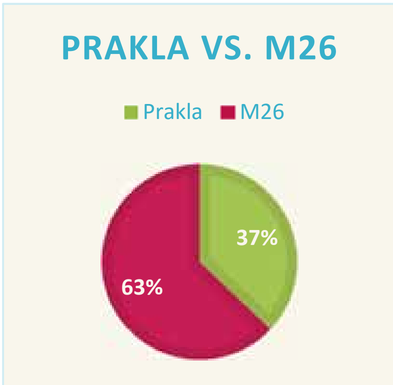
Deployed sensors (receivers) :

	WINGS	RAUs	TOTAL
Deployed	491	4451	4942
Swap		4378	4378
Index (several positions)	1	10	11
No data	30		30
TOTAL	**4972**		



Vibrated points:

	Prakla	M26	TOTAL
Done Vibrations	9715	16503	26218
High Drive 80%	8367	16137	24504
Low Drive 40%	1348	366	1714
2nd round of vibration at the end	187	810	997
Skipped points in production	382		382
Skipped points at NANGIS	936		936
TOTAL	**27215**		



The receiving and source SPS have been sent in the deliverables and these files have all the necessary information to perform the processing.

The description of the information in the SPS are available in the headers of its files.

As a precaution, we decided to remove 997 points at the end of the project that had been acquired during heavy rainfall. Indeed, we had not yet collected the data to be able to analyse the impact of this precipitation on the data. After retrieving the data, we did an analysis regarding these points and we noticed that the rain had a very low impact (see image below).

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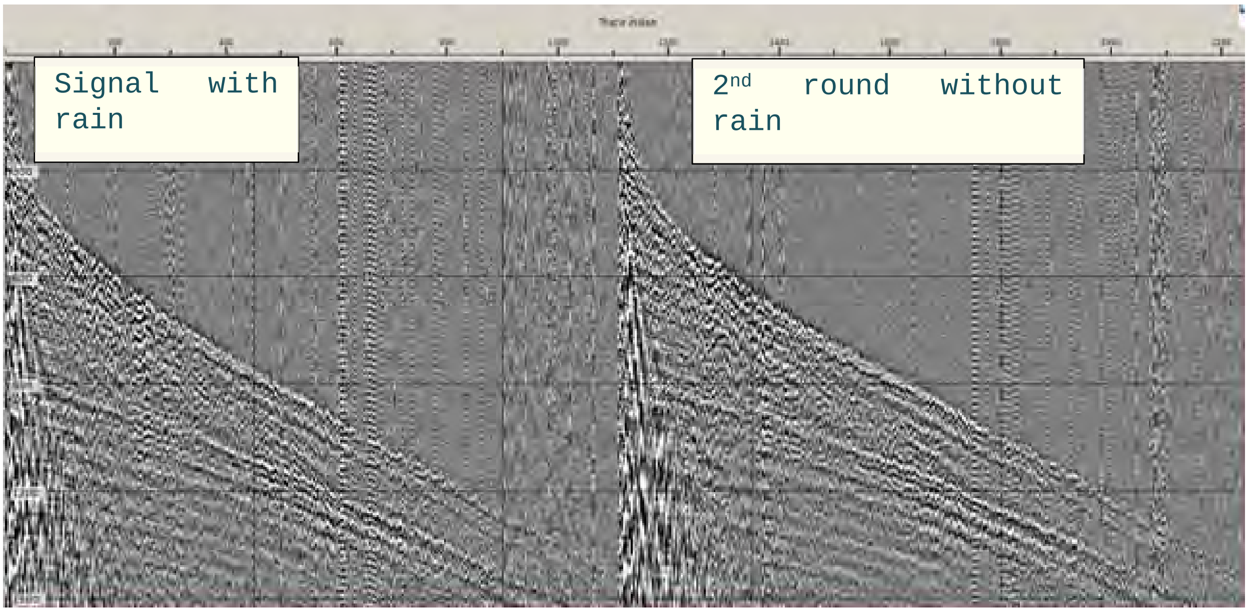


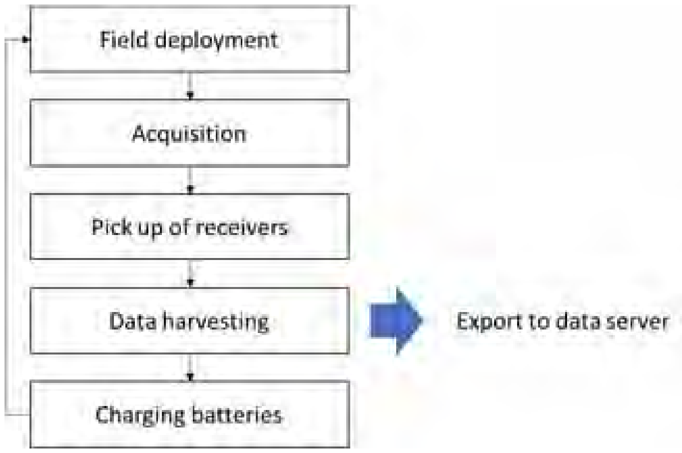
Figure 6-33: Noise analysis with and without rain for the same vibrations

7. Data quality control & processing

7.1. Harvesting and exporting continuous seismic data

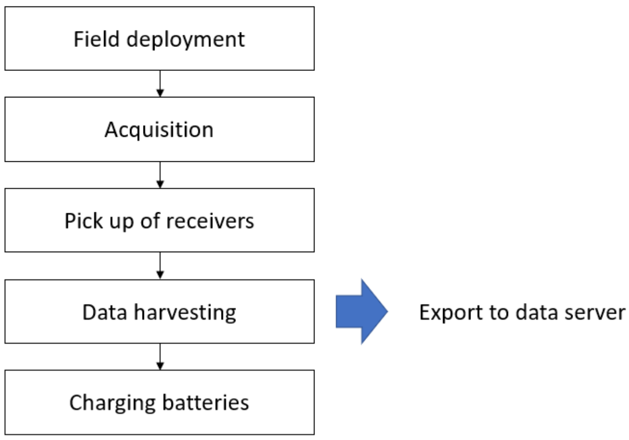
7.1.1. RAU

The seismic data were progressively harvested as the RAUs were picked up from the field. While plugged on the racks, their batteries were recharged so that they could be deployed again for the next rotation. The following flowchart illustrates the cycle of the RAUs:



7.1.2. WINGS

The Wings had a sufficient battery life to last the duration of the acquisition. Therefore, they were picked up after the last vibration:



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7.2. Source events

The force of each source point was stored in the server. Those files are mandatory to extract and denoise each record from the blended continuous seismic data. It is also important to keep all the events: valid and invalid. Indeed, while an interrupted vibration is invalid, it potentially pollutes another one. Therefore, it is taken into account in the separation process but no seismic record will be exported.

In total, 27455 have been used for the separation of the 27215 final records.

Daily, the forces were analysed in order to judge the quality of the vibrators (amplitude, phase and distortion):

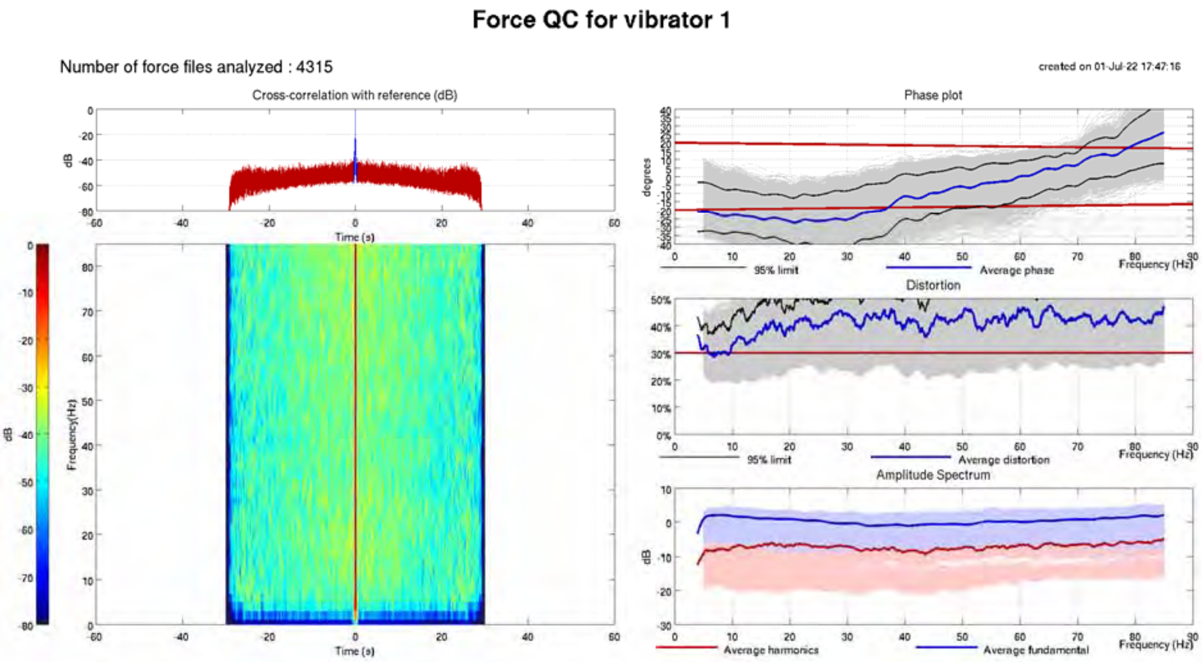

Figure 7-1: QC distortion / phase / amplitude of vibro 1 (Prakla)

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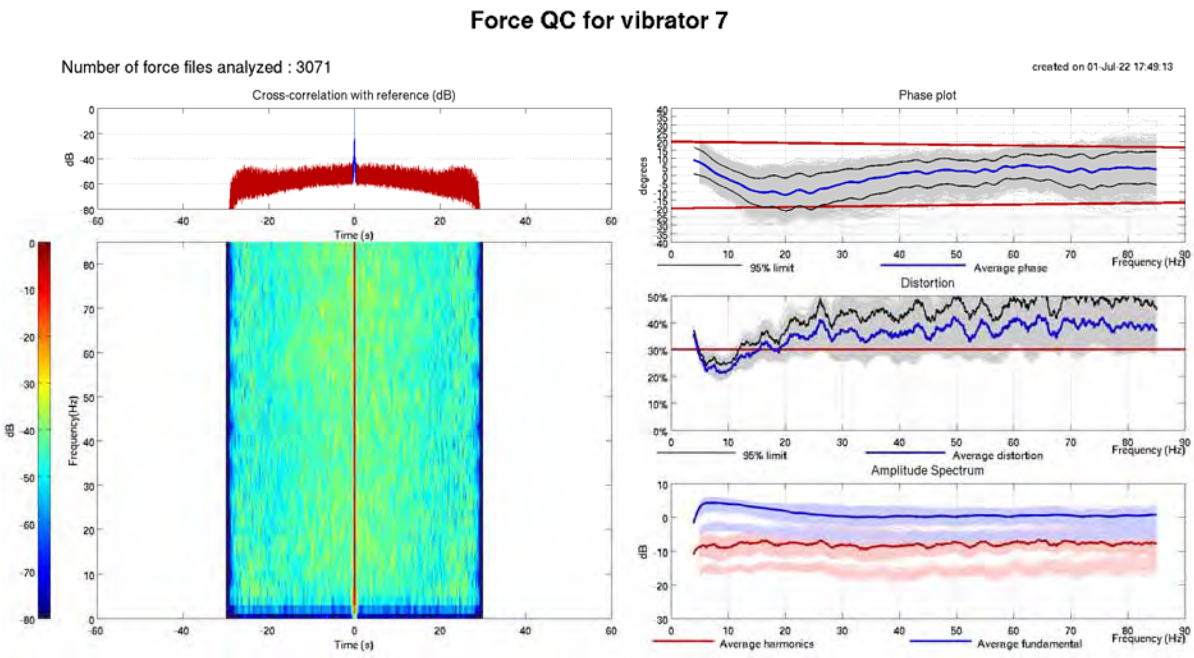

Figure 7-2: QC distortion / phase / amplitude of vibro 7 (M26)

7.3. Data security

The raw data were stored into 2 physically distinct devices (NAS) and exported to the server of the QC department to be processed. During the demobilization, a copy of the RAW data and the processed data was sent to S3 office in Guingamp (France). Another copy was kept by the operator to finalize the separation of the seismic records.

7.4. Data integrity

The continuous seismic data were scanned to verify their integrity. This process is based on the RMS of the signal of each receiver and allows to detect any extraction or export issue from the recording system. The results can be plotted as follow:

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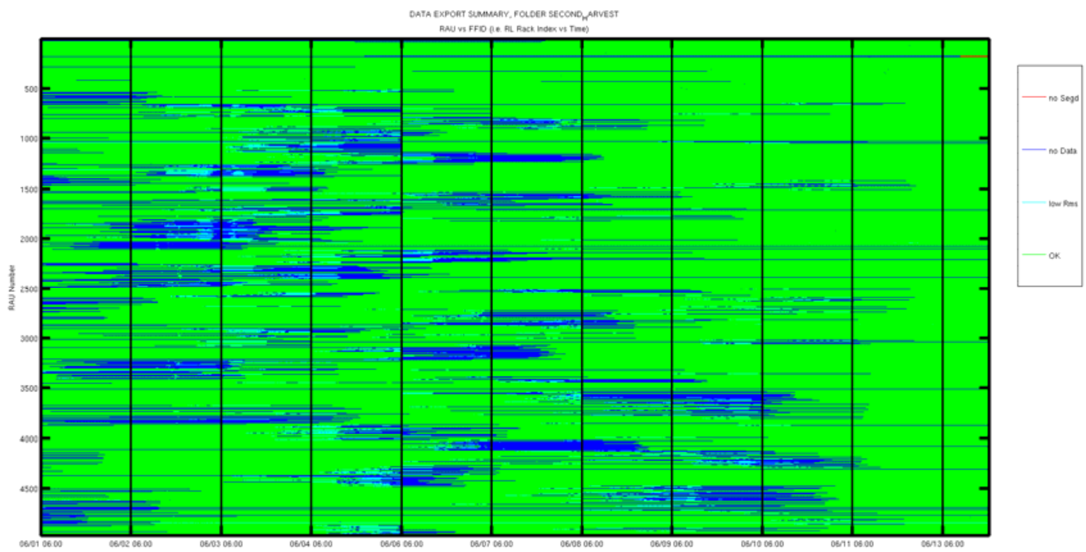

Figure 7-3: Control of data integrity: device vs. time vs. RMS signal

7.5. Denoising and separation of seismic records

Seismic data were sorted according to their location in the rack and the day of acquisition. The denoising was made in RP gather according to the following flow:

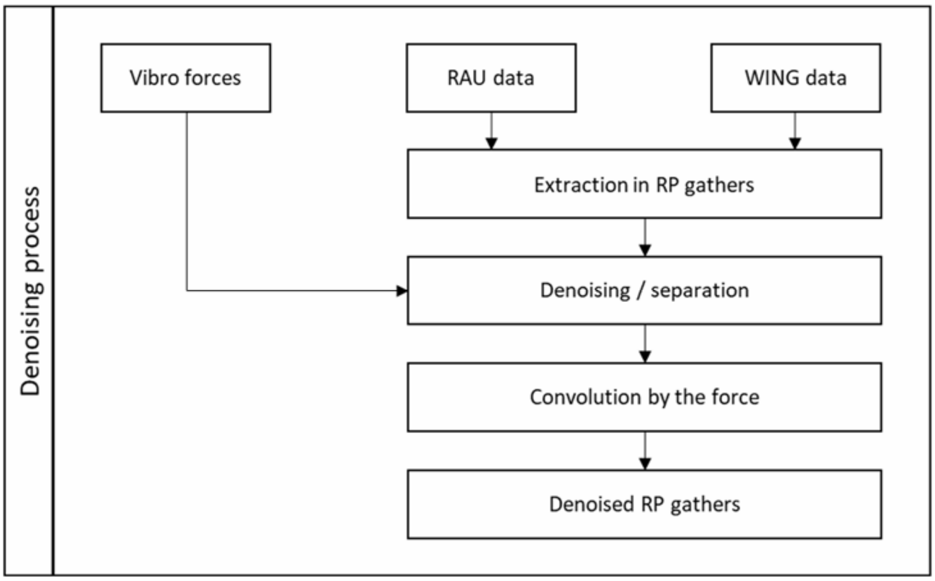

Figure 7-4: Separation process flowchart

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At this step, the RP gathers already showed an excellent quality of the recorded seismic data.

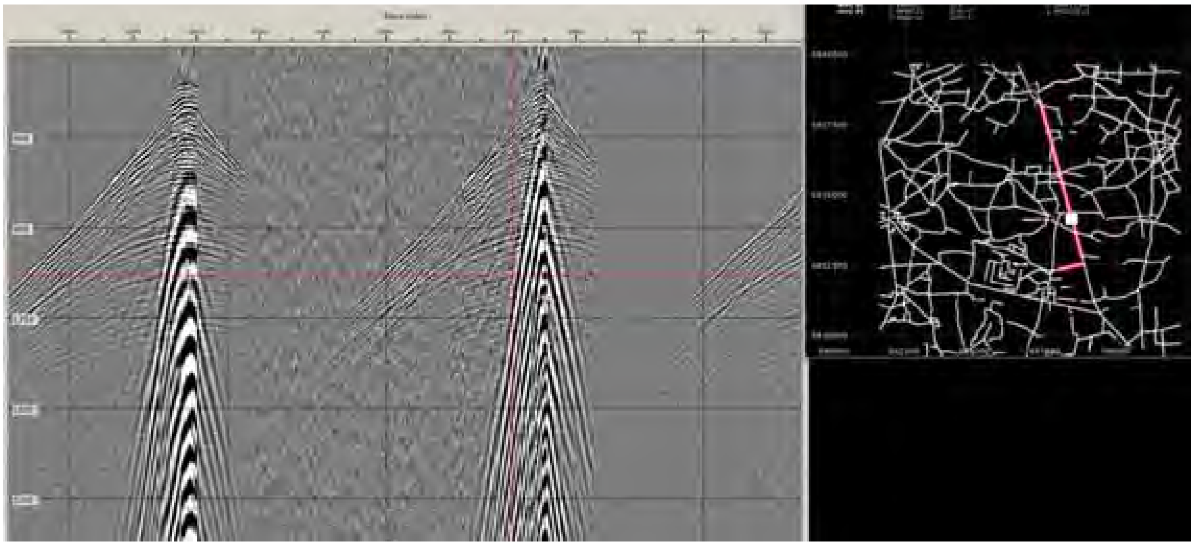

Figure 7-5: Example of RCV gather after separation and force convolution

7.6. Assignation

The assignation consists of linking a recording device to a seismic point for a specific duration. Getting the right information from the field was a challenging point as the recording devices were rotated in the field (RAUs). The RP interval was sufficiently large to use an algorithm to assign the Line-Point to each device according to the GPS recorded positions.

7.6.1. Automatic assignation algorithm

The segmentation (120 seconds) of the continuous seismic data used for the data integrity check also gave the GPS position of each device. The device was assigned to the closest RP within 25m of the GPS position. Still some conflicts of assignation were to be solved: several devices linked to a single position during the same period, no RP within 25m.

7.6.2. Comparison and manual assignation

The GPS positions of a single device were projected on a 15m*15m grid. The number of impacts in each bin was counted. The distribution determined the 2 bins that were the most impacted. Those two positions were compared to the theoretical positions and to the field report in order to decide of the final assignation.

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7.6.3. Results and summary

The following flowchart illustrates the implementation of the method:

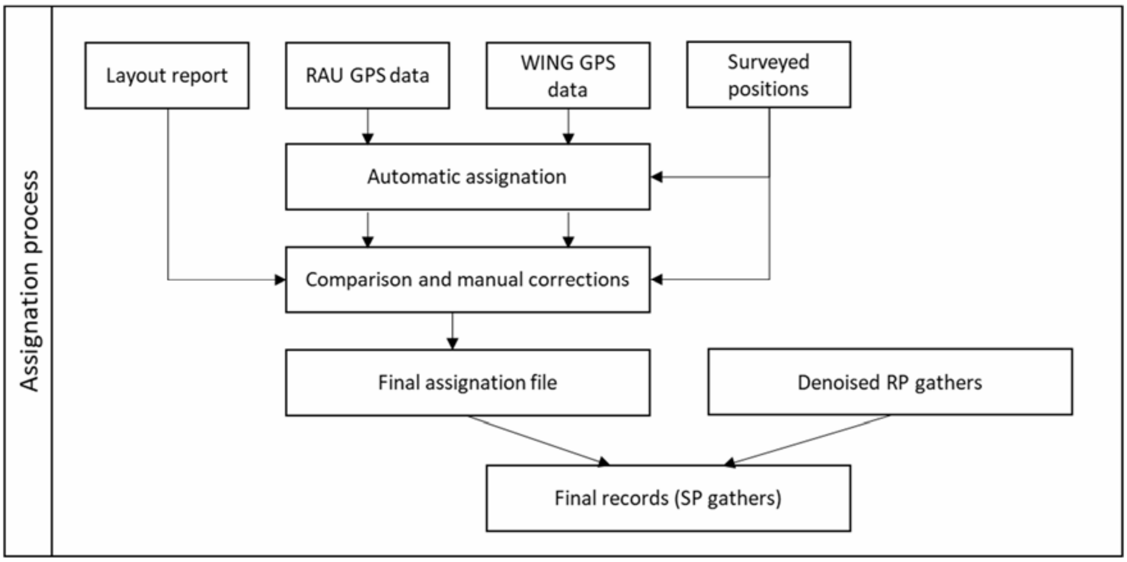

Figure 7-6: Assignation flowchart

The combination of the automatic and manual methods solved incoherencies from the field reports. Indexes could be created for some locations where the devices had been moved without notifications.

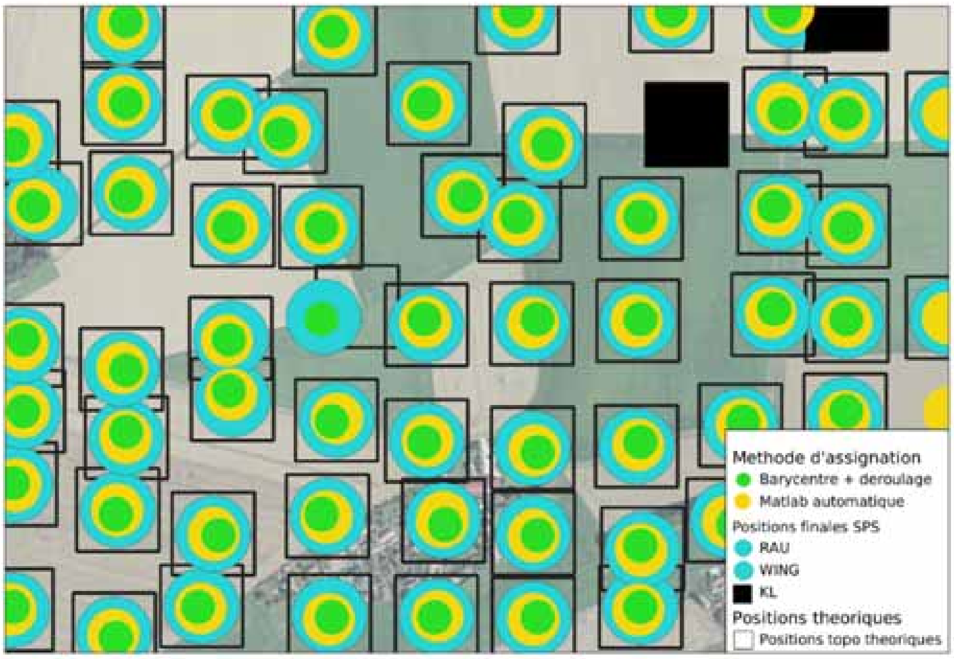

Figure 7-7: Comparison between surveyed positions, the device GPS values and the reported values from the layout teams

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7.7. QC and geometry control

7.7.1. Number of traces

A set of 50ms SP gathers had been produced in order to count their number of traces. This simple QC highlighted that 900 force files were missing from acquisition day 161. Those force files have been re-generated thanks to the RAUs that record the vibrator signals (from mass and plate accelerometers).

7.7.2. Geometry control of source points

The validation of the source points took place daily according to the following quality attributes:

- Measurement mode = 5 (RTK Float Mode)
- HDOP <= 5
- Number of satellites >= 5

The plate location of the vibrations that were out of specifications were marked by the operator so that the surveyor could then go and retrieve the position.

The coordinates of the SPS files were applied to the final seismic records. LMO and simple elevation statics were applied to control the geometry. This QC identified 6 points that had aberrant elevation values (100m differences with closest neighbours).

Elevations were corrected in the final SPS files.

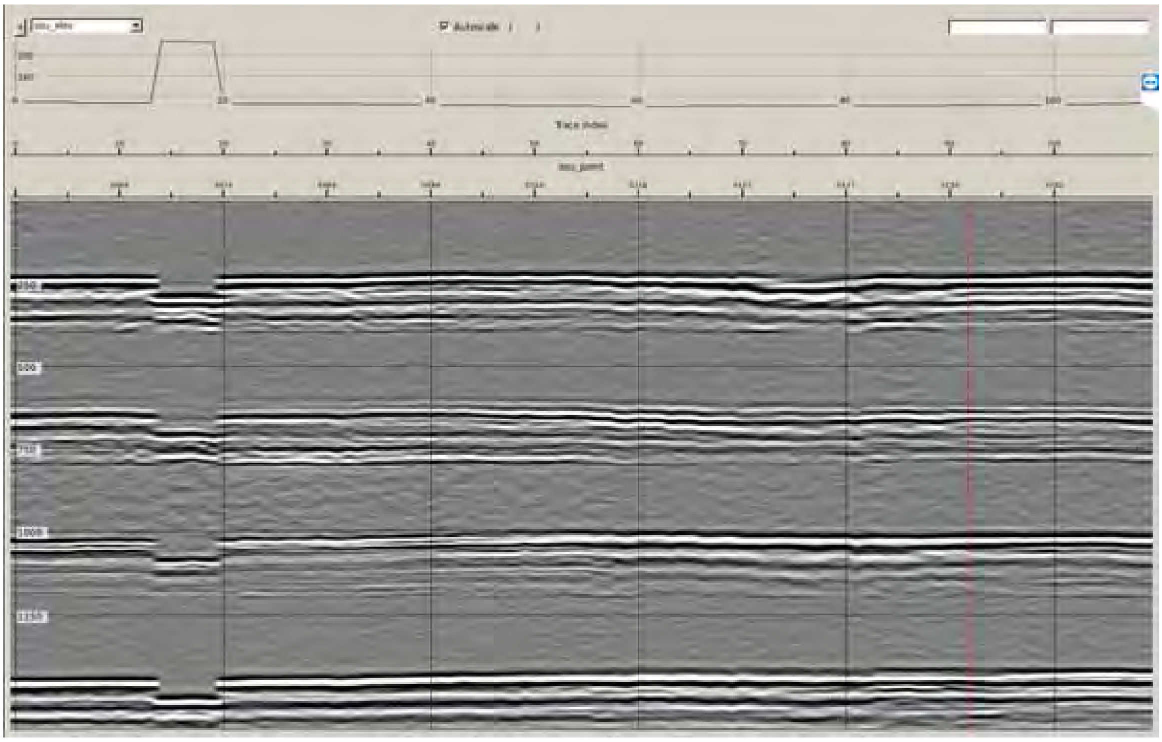

Figure 7-8: LMO + elevation static QC display showing incoherency of 6 SPs

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7.7.3. Geometry control of the RPs

In addition to the assignation control, the receiver geometry was also checked for each RP following the same methodology as the SP.

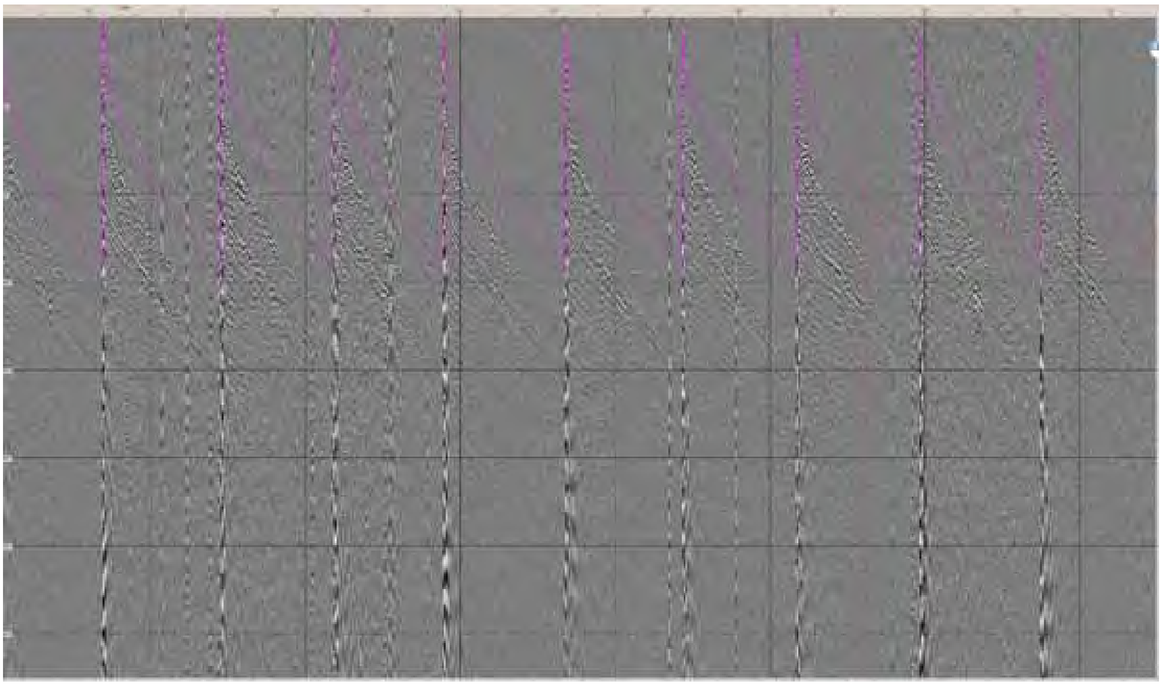

Figure 7-9: Geometry QC before LMO watching the first arrivals

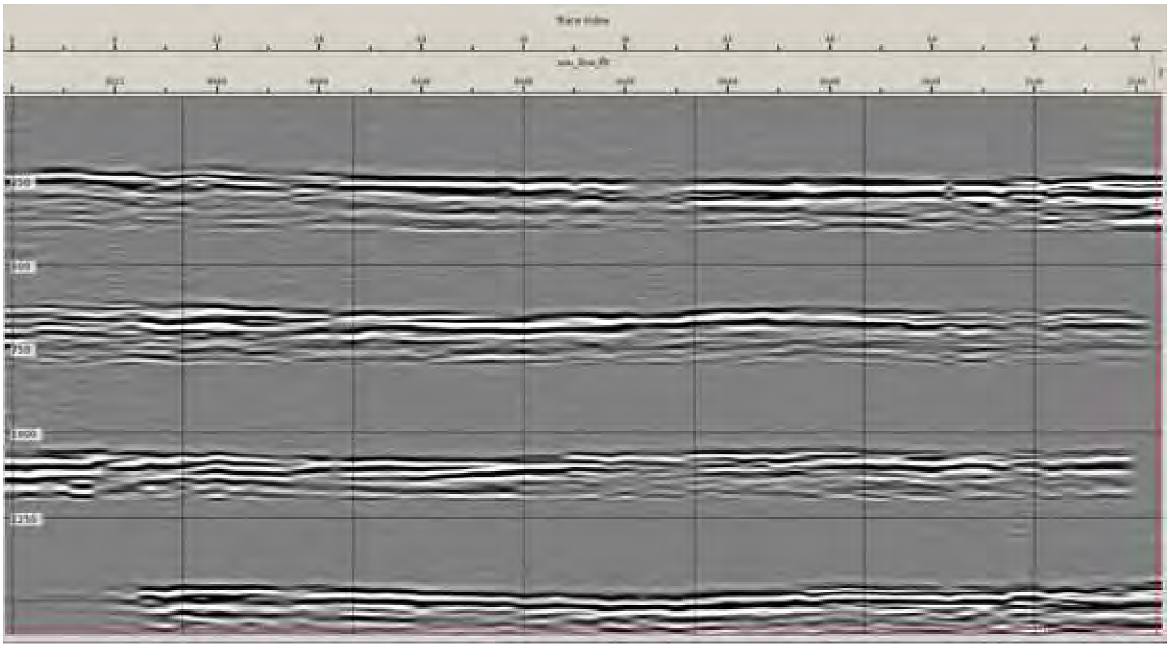

Figure 7-10: LMO + elevation static QC display of RP

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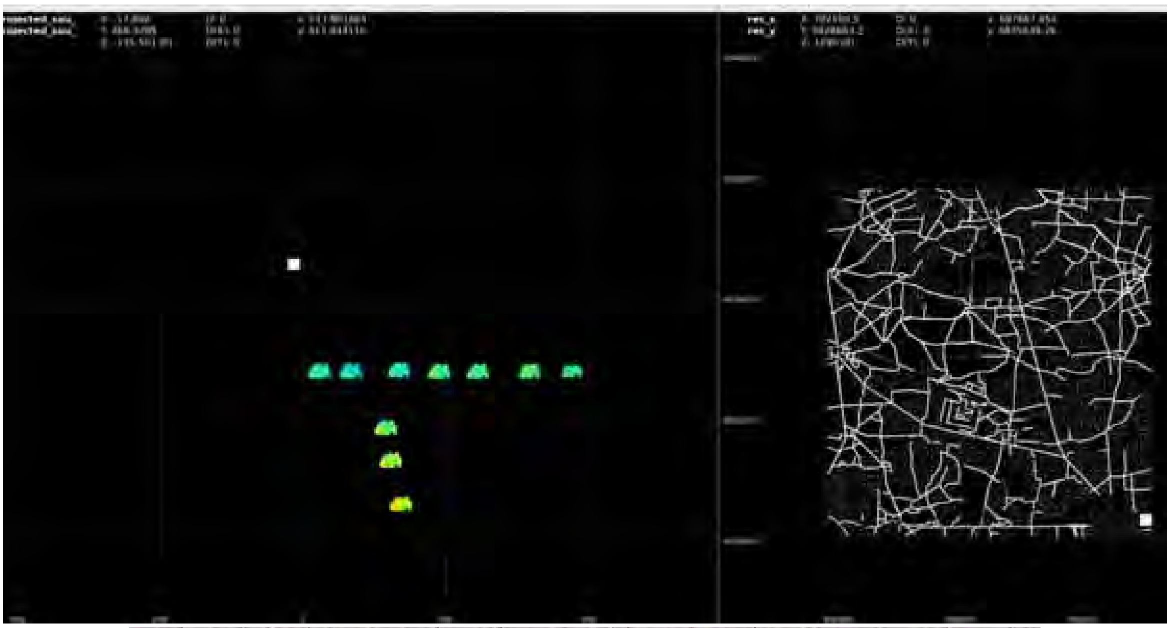
7.7.4. RMS QC

The RMS of each RP was computed and plotted. Source of noise were easily identified (high voltage lines, traffic, etc.).



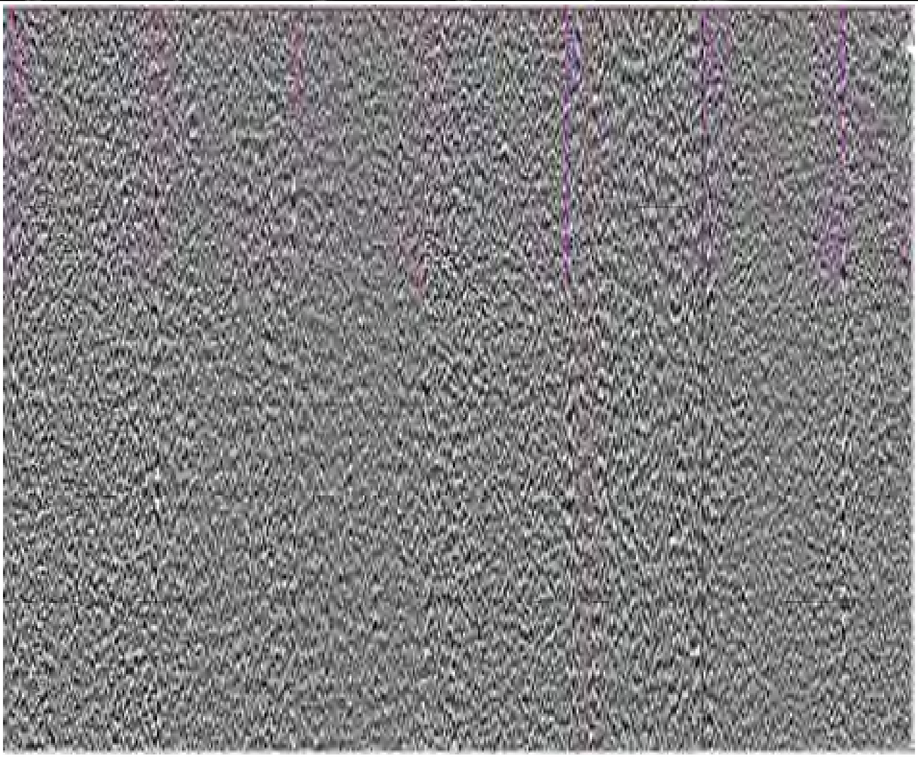


Figure 7-11: Noisy data due to the urban activity in Nangis

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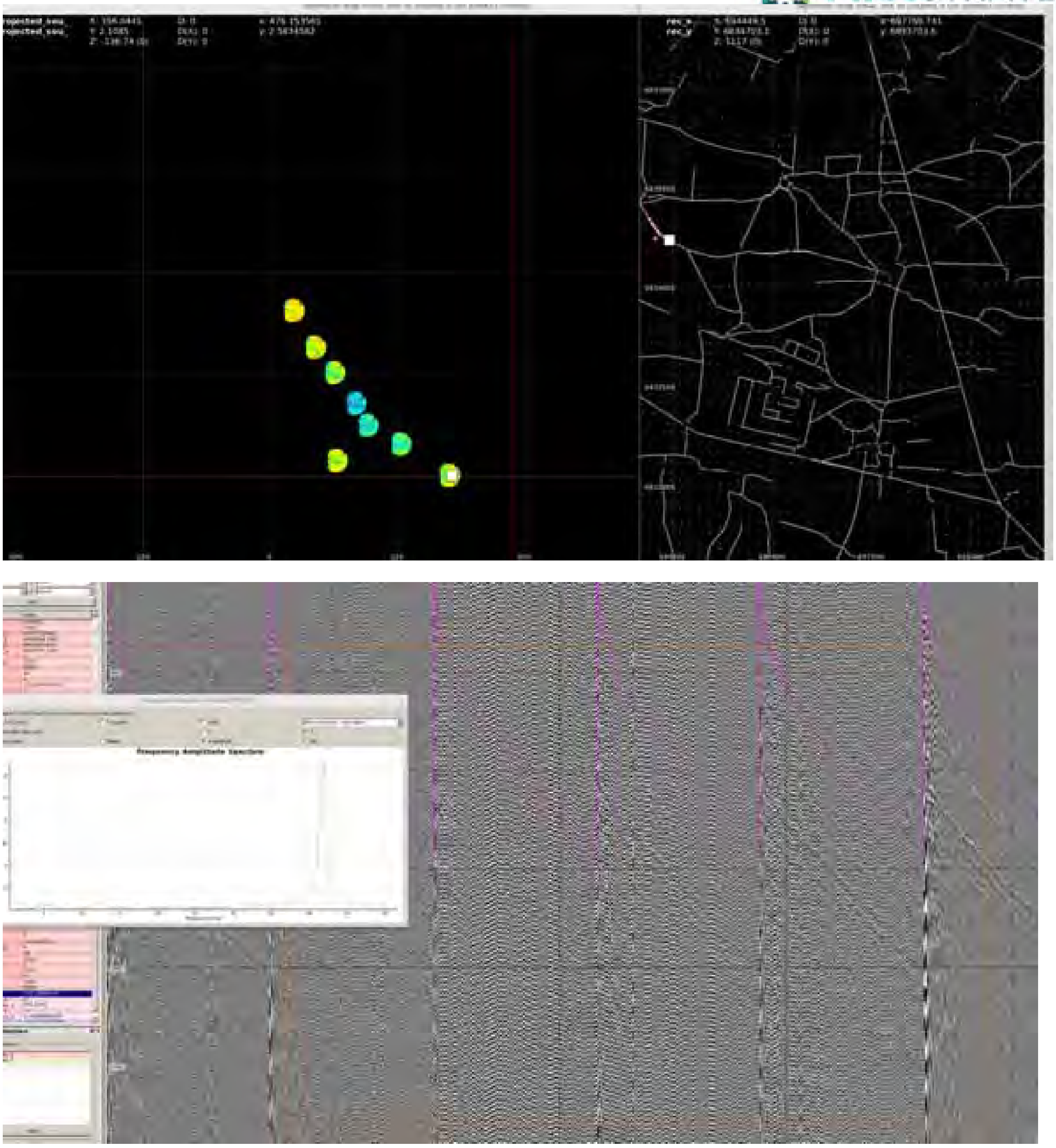

Figure 7-12: Electrical source polluting the recording device

7.7.5. Exporting the final data

On the 4th of July 2022, a set of 492 SEGD files was sent to CDP (Day 158, Vibrator 3, 2D line acquired along departmental road 201) so that they could control the SEGD format as well as the SPS.

A first set of denoised records was ready on the 10th of July, but the QC operator judged the quality unsatisfactory (missing forces, assignation errors, geometry errors). It took about a month to solve and re-run the denoising tasks. The final data were sent to CDP on the 7th of August 2022, eventually.

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8. Preliminary seismic interpretation

Results presented here correspond only to the preliminary interpretation of the 3D seismic data acquired and presented before. A regional scale interpretation will be proposed and show as well depth of the main studied objects. Detailed mapping of specific horizons, complemented with attributes map of the reservoir will be detailed in the next deliverable 2.7 – Geological conceptual model. Consequently, after brief presentation of the geological context followed by the data and methodology used, results of preliminary interpretations will be proposed on the full sedimentary pile with a focus on the targeted reservoir complex.

8.1. Geological context – The Paris Basin and the Dogger reservoir

The Mesozoic / Cenozoic Paris Basin correspond to an intracratonic sedimentary basin, with a sag geometry, lying unconformably over Paleozoic basement (Figure 8-1). The tectono-sedimentary evolution of this basin is mainly influenced by regional geodynamical events associated to extensional stages of the Mesozoic opening of the Alpine Tethys, Atlantic Ocean and Bay of Biscay, and compressive events of the Late Cretaceous-Cenozoic Pyrenean and Alpine orogenies. This long-term geological evolution resulted in eleven major tectono-sedimentary cycles from the Triassic to the Tertiary. These cycles are detailed in the Figure 8-1. In the PilotStratgey project, the reservoir complex is associated with the transgressive stage of the Lower Bathonian – Oxfordian cycle. This interval corresponds to the growth of the Dogger Carbonate Platform.

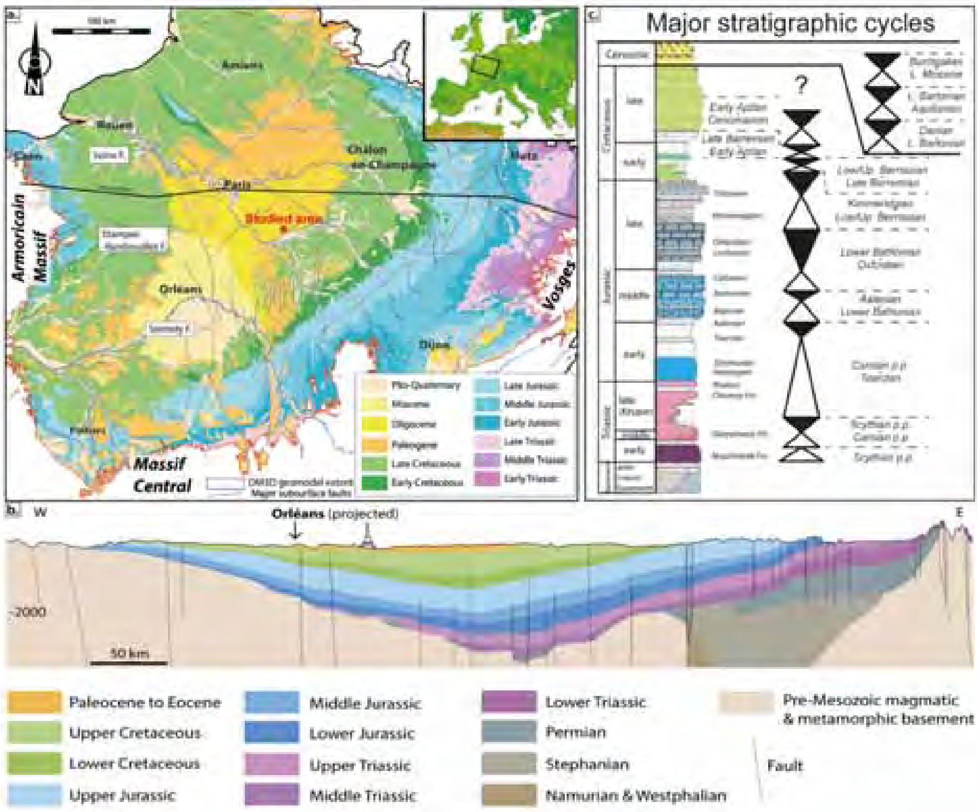

Figure 8-1: Structuration of the Paris Basin and main stratigraphic sequence recorded. Figure modified from Mas et al., 2022.Stratigraphic sequence from Guillocheau et al., 2000

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During the Dogger (Middle Jurassic), the Paris Basin was located at subtropical latitudes and was covered by an epicontinental sea open to the Tethys to the southeast, and the proto-Atlantic to the southwest. However, the latter was less well connected to northern oceans because of the exposed London-Brabant and Armorican massifs (Figure 8-2).

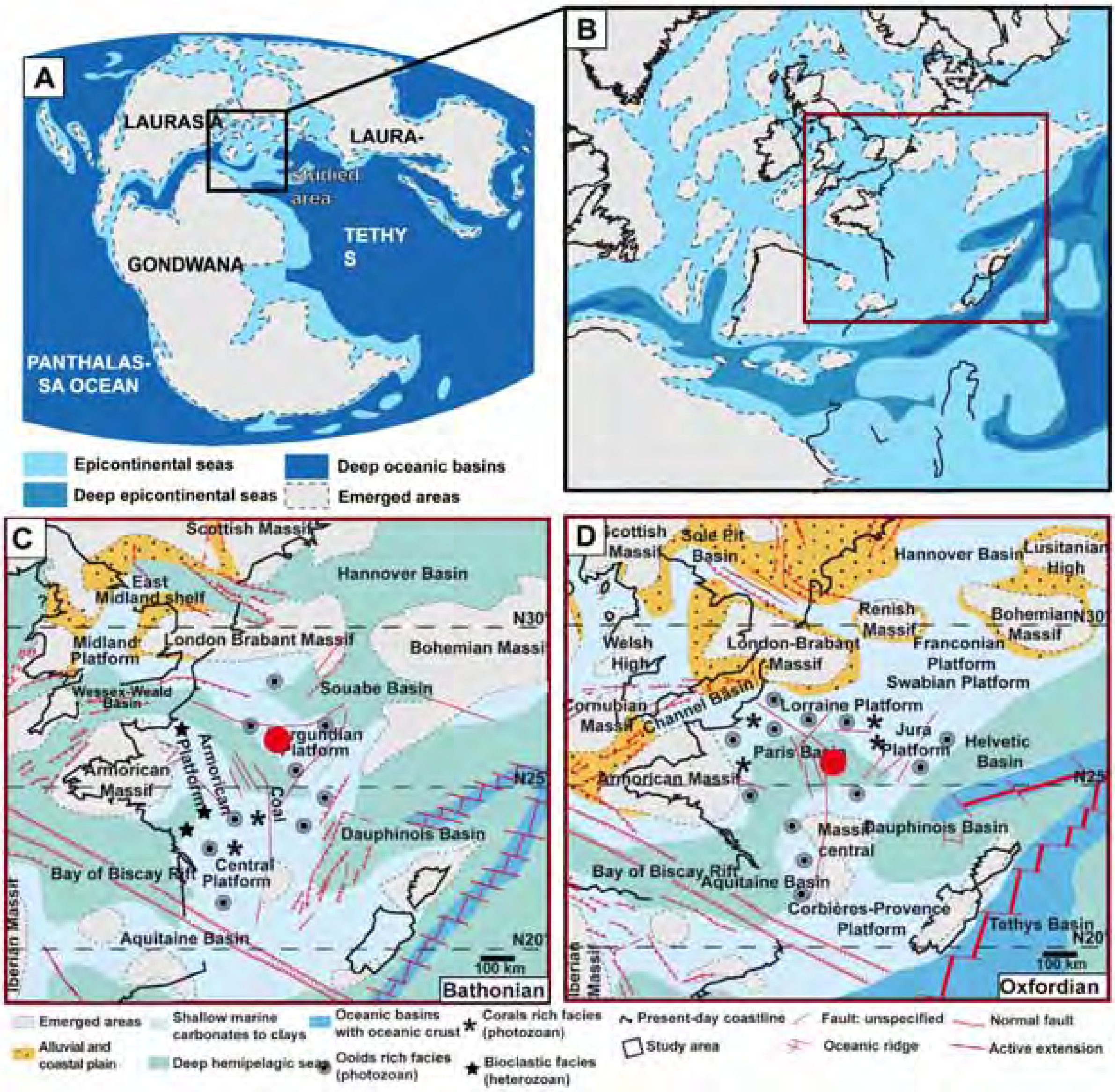

Figure 8-2: Paleogegraphic map of the Paris Basin during the Dogger (Middle Jurassic) and Malm (Upper Jurassic). Figure from Andrieu 2016.

After the early to late Bajocian carbonate crisis, deposition of open-marine marls (Marnes à Ostrea acuminata formation) was the result of a major flooding event across the Bajocian platforms. Following this major transgressive stage, and during the Bathonian, carbonate ramps developed again around and within the Paris Basin.

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The Early Bathonian recorded the first stage of development of this ramp, with deposition of argillaceous limestone and associated in our study to the general prograding stage of the ramp.
The Middle Bathonian and Late Bathonian corresponded to the proper establishment of the ramp, recorded in our study as the aggrading stage. Two main depositional environments at the scale of the study area are present:

- A high-energy barrier inner-ramp characterized by grain-supported textures (grainstone, packstone) with abundant ooids, peloids and bioclastic debris from bivalves, echinoderms, bryozoans and gastropods (Oolithe Blanche Formation),
- A typical low-energy inner ramp lagoon characterized by dominant mud-supported textures (mudstone, wackestone) with oncoids, peloids, gastropods, green algae and locally showing evidence of subaerial exposure (Calcaire de Comblanchien).

In the study area, the *Oolithe Blanche* formation passes vertically to the lagoonal facies of the *Calcaire du Comblanchien*, following a general regressive stage. The latest Bathonian deposits recorded an extensive flooding of the ooid-dominated system, with the deposition of a bioclastic-dominated ramp that developed during the Early Callovian in the study area (Dalle Nacrée Formation) followed by a thick succession of marls.

The reservoir complex of this study corresponds vertically to 1) the permeable *Oolithe Blanche* Formation, 2) the semi-permeable formation of *Calcaire du Comblanchien* (with fracture porosity), 3) the second reservoir *Dalle Nacrée* Formation and finally 4) the Callovian marls, representing the caprock *sensu stricto*. High-energy depositional settings of the ramp and surrounding bioclastic rich patches represent the main reservoir facies. The Oolitic grainstones of the ramp system were deposited principally during the Bathonian. Although the Dalles Nacrées (Callovian – Upper Dogger) are the (fractured limestone) target of the Charmotte oil-field in the South of the Grandpuits area, their potential for CO_2 storage is low, as they are thin (15-40 m-thick) and have only fracture porosity.

8.2. Available Data & Methodology

The French study area is located in the Paris Basin, at 60 Km Southwest of Paris next to the Nangis locality. This area has been a preferential target for oil exploration in the second half of the 20th century, as shown in Figure 1b with the numbers of wells used in our study. Nowadays a high volume of wells, well logs, and cores data are in the public domain and used in this study to understand the "Oolithe Blanche" Formation, the targeted reservoir in the French Area for PilotSTRATEGY Project. Preliminary interpretation of the newly acquired seismic data has been conducted on the base of the preliminary processed data and framed by 4 wells present in the area. Hereby, characteristics of the well and seismic data used for preliminary interpretation, and the new methodology used for seismic interpretation is presented here.

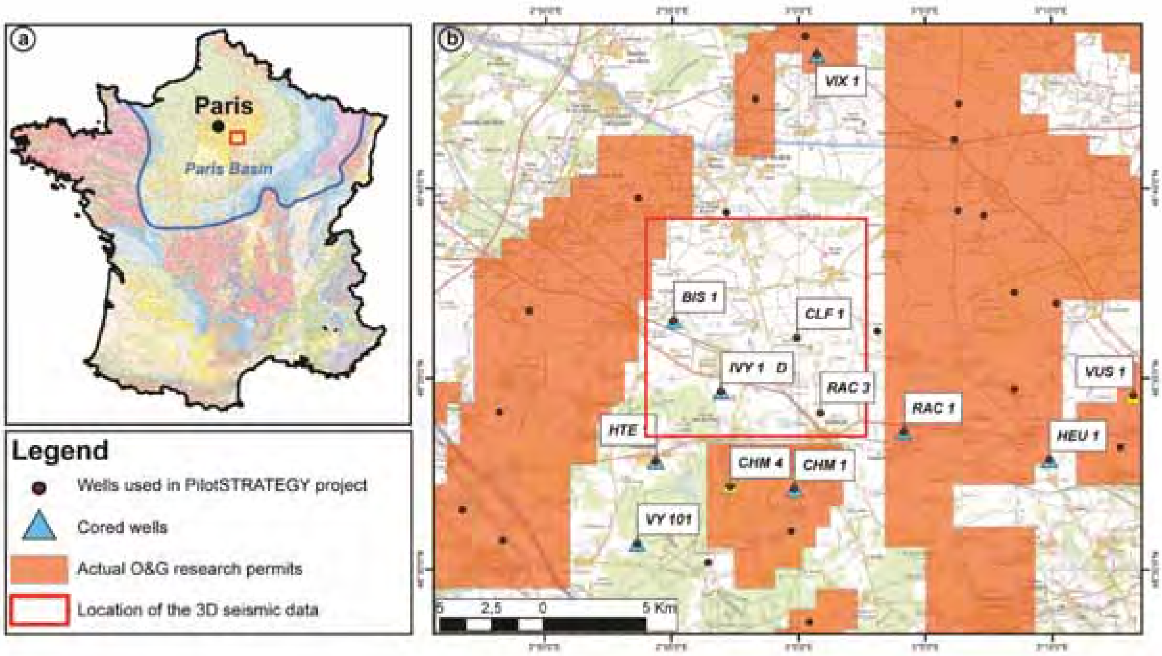

Figure 8-3: Location of the studied area (a) and location of wellbores from oil and gas exploration present in the seismic acquisition area

8.2.1. Seismic data

Detail concerning seismic data acquisition, processing and QA/QC has been presented in previous sections of this report. Seismic interpretation proposed here has been conducted on the PSTM seismic cube processed by CDP Consulting Company. Details of the processed seismic data are presented in Table 8-1. This table details characteristics of the seismic cube with the numbers of Inline and Crosslines, vertical domain, CRS and other useful information.

Table 8-1: Detailed of the processed seismic data cube

File Size		X-line	
Volume Size	924.05 MB	X-line Min	79
Data Type	Float	X-line Max	619
Vertical Domain	TWT	Z	
Size		Z Min	0 ms
Nb In-line	577	Z Max	3100 ms
Nb X-line	541	Resolution	
Nb Z	776	SRD	0 m
Unit		In-line	20 m
Spatial	Meter	X-line	20 m
Vertical	Millisecond	Vertical	4 ms
Original CRS		Dimensions	
Name	RGF93 / Lambert-93	In-line	10820 m
Authority	EPSG	X-line	11540 m
Authority Code	2154	Z-Range	3104 ms
In-line		Area	1,24863e+08 m²
In-line Min	58	Seismic cube name :	
In-line Max	634	CCUS3D_PSTMstack_postproc	

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8.2.2. Well Data

In the seismic area, 4 wells from oil exploration are present and used to support seismic interpretation and facies calibration. Well locations and their deviations are presented in the Figure 8-3 and Figure 8-4. A detail of the well data are presented in the Table 8-2. From the latter, only one well has a checkshot calibration and a velocity law. This allows the team to propose a precise seismic / well tie and achieve accurate picking of the full sedimentary pile.

Table 8-2: Description of wellbore position and logs located in the studied area

Well Name (ID)	Coordinate	TD / TVD	Interval Cored	Logs	time-depth relationship
Iverny – 1D - IVY-1D	X: 696196 (m) Y:6830833 (m) EPSG: 2154	2948 m / 2635 m	2082-2116m (MD) Dalle Nacrée / Comblanchien / Oolithe Blanche	Depth (m) ; Bit size (in) ; Caliper (in) ; Bulk density correction (g/cm^3) ; Sonic (us/ft) ; GR (API) ; Neutron porosity (v/v) ; Bulk density (g/cm^3) ; Resistivity medium (Ohm/m) ; Resistivity Depp (Ohm/m) ; Spontaneous potential (mV)	Null
Bisseaux 1 - BIS-1	X: 693893 (m) Y: 6834280 (m) EPSG: 2154	2627 m	1837-1879m (MD) Dalle Nacrée / Comblanchien /	Depth (m) ; Bit size (in) ; Caliper (in) ; Bulk density correction (g/cm3) ; Sonic (us/ft) ; GR (API) ; Neutron porosity (v/v) ; Bulk density (g/cm3) ; Resistivity medium (Ohm/m) ; Resistivity Depp (Ohm/m) ; Spontaneous potential (mV)	Null
Rache 3 - RAC3		2639 m	No Core	Depth (m) ; Bit size (in) ; Caliper (in) ; Bulk density correction (g/cm3) ; Sonic (us/ft) ; GR (API) ; Neutron porosity (v/v) ; Bulk density (g/cm3) ; Resistivity medium (Ohm/m) ; Resistivity Depp (Ohm/m) ; Spontaneous potential (mV)	Null
Clos Fontaine 1 - CLF-1		2644 m	No Core	Depth (m) ; Bit size (in) ; Caliper (in) ; Bulk density correction (g/cm3) ; Sonic (us/ft) ; GR (API) ; Neutron porosity (v/v) ; Bulk density (g/cm3) ; Resistivity medium (Ohm/m) ; Resistivity Depp (Ohm/m) ; Micro Resistivity (Ohm/m) ; Spontaneous potential (mV) ; Photoelectric Factor B/E ; Uranium (ppm) ; Thorium (ppm) ; Potassium (%)	Present

Available logs present in the study area have been used for seismic interpretation along with seismic well tie work. CLF-1 well is the only one with a or time-depth relationship which let us calibrate DT and propose a proper time depth conversion of main interpreted horizons. Seismic interpretation followed horizons calibrated on this well. CLF-1 or time-depth relationship has been extrapolated to the 3 other wells with a specific shifting as 0ms for BIS-1 Well, -18ms for RAC-3 well and -15ms for IVY-1D well.

Then QA/QC has been done between reservoir markers (MFS and top reservoir) with interpreted horizons based on the CLF-1 well. Maximum shifting observed between horizons and their markers tie well correspond to 6ms. This is acceptable considering the 4ms vertical resolution of the seismic data.

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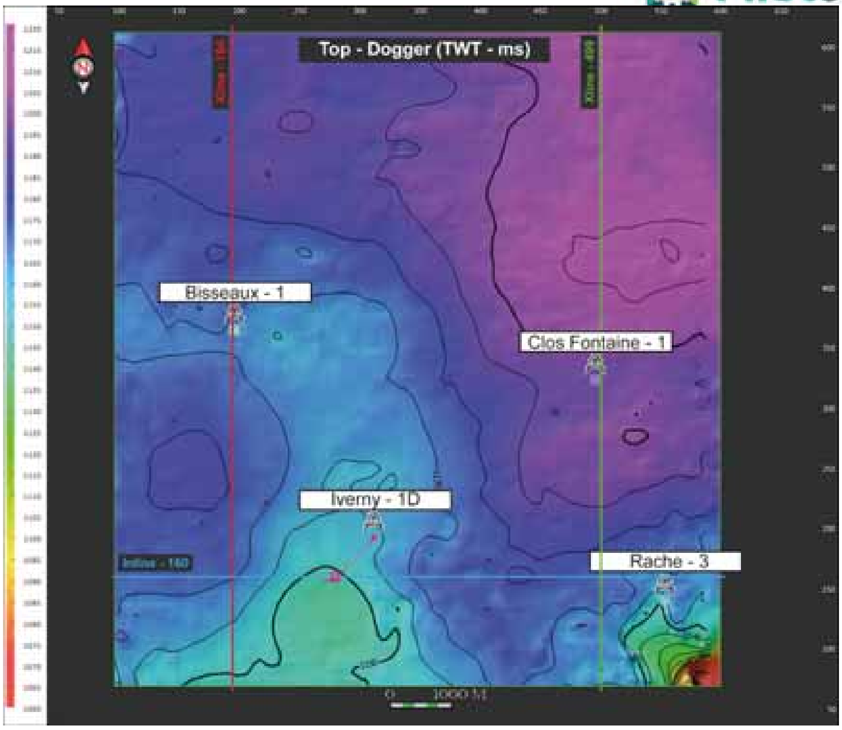

Figure 8-4: Location map presenting position of wells, and Xlines and Inlines shown as example.

8.2.3. Seismic interpretation methodology

The 3D seismic analysis was conducted using PaleoScan software, which uses full-volume and semi-automated interpretation algorithms to interpret 3D seismic data. Specific methodology and workflow are proposed in Paumard et al., 2019. Following description of the workflow from Paumard et al., 2019 article, the standard workflow comprises four main steps that can then be refined at different scales of observation to obtain higher resolution interpretations. This four steps corresponds to:

(1) **Model-grid computation** - This first step consists of calculating a geological model grid from the original seismic volume. This model is computed by establishing links among elementary horizon patches, which are based on the signal amplitude of neighbouring traces throughout the 3D seismic data.

(2) **3D RGT Model Computation** - The second step consists of calculating a 3D RGT (RGT Stands for Relative Geological Time) model or the 3D geomodel, which corresponds to the vertical interpolation of the previous model grid and where a relative geological age is associated with each point of the volume. Because each horizon is assigned a negative or positive integer value within the model grid, the vertical interpolation allows for calculating a RGT model, where seismic horizons are fully modelized across the entire seismic survey with continuous decimal values.

(3) **Horizon Stack computation** - The third step, a horizon stack (i.e., set of full-volume horizons) can be extracted from the 3D geomodel. The 3D geomodel corresponds to the full volume seismic data interpreted in a relative geological time domain, from which an unlimited number of chronostratigraphic surfaces can be generated. These surfaces correspond to stratigraphic horizons (i.e., stratal slicing) as opposed to horizontal surfaces cutting through the 3D volume (i.e., time slicing).

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(4) **Sequence stratigraphy model computation** – this fourth part involves the identification and definition of seismic stratigraphic surfaces and seismic units. This last stage follows the basics of the seismic stratigraphic interpretation methods developed in the 70's by EXXON mobil research team (see Vail et al., 1977a). Seismic unconformities are defined by the determination of stratal terminations as downlap, onlap, toplap, erosional truncation, and offlap. Each seismic unconformity defines the limit of a depositional sequence. A seismic sequence, sensu Mitchum et al., 1977b, is defined as a "stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities or their correlative para-conformities". Thanks to the Horizon stack computation, all chronostratigraphic surfaces are mapped allowing the definition of major unconformities.

A characteristic of the studied area is the absence of major unconformities. In order to propose a proper seismic units framework, seismic units' limits followed major sedimentation sequences. Consequently, seismic interpretation followed strictly the tectono-sedimentary framework proposed for the Paris Basin.

8.3. Preliminary results

After a brief presentation of the detailed seismic stratigraphic framework and the main surfaces interpreted, preliminary results obtained on the reservoir complex (structures, depths, etc.) will be presented. The latter is divided into two parts, with the main structuration of the area and details of sedimentary pile.

8.3.1. General framework of the sedimentary pile.

Sedimentary pile described here is divided into 17 sedimentary layers delimited by 18 horizons mapped all along the 3D seismic data. These units spanned from Cenomanian to Triassic. Sedimentary intervals present above and below the studied pile are not investigated because of the lack of age and facies calibration between seismic and well data. Names and stratigraphic position of horizons that define seismic units boundaries are presented in Figure 8-5. Targeted reservoir complex is located between the Top_Oxfordian-Up horizon and the Top_Bajocian. Four other horizons sub-divide this interval. In stratigraphic order, Top_Bajocian indicates the bottom of the reservoir complex and the Top_Bathonian defines the top of the first reservoir interval, which includes the *Calcaire du Comblanchien* Formation relatively tight but with very minor porous/permeable drains. The Top-Callovian-low mark the top of the Dalle Nacré formation, which corresponds to the second reservoir interval, regionally associated to oil reservoir. Then, Top_Callovian-Up and Top_Oxfordian-Inf indicate respectively top of the clayey interval and marls which corresponds to the first caprock. Finally, the Top_Oxfordian-Up signs the top of the reservoir complex with the top of the second caprock associated to tight limestone.

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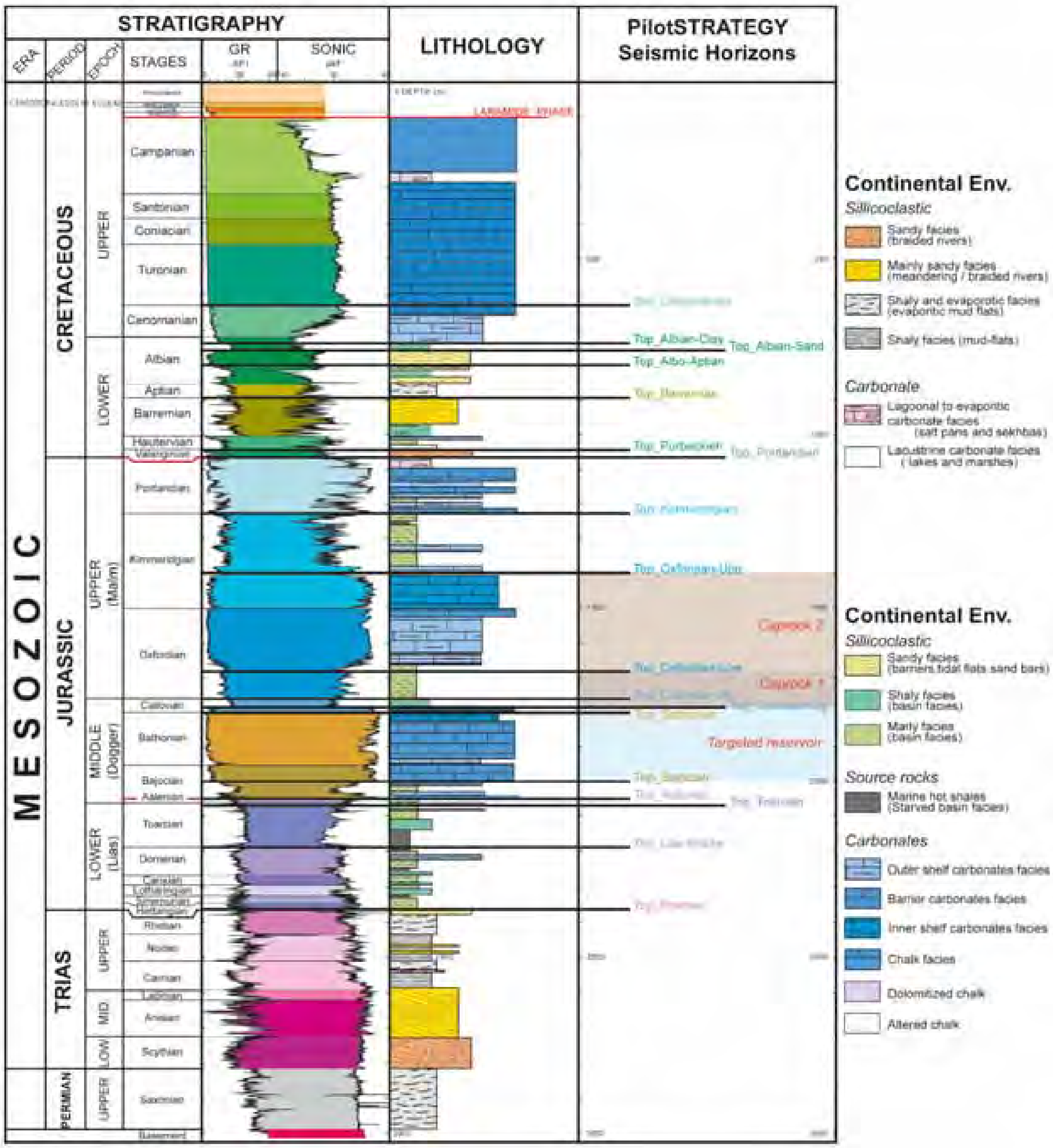

Figure 8-5 : Figure representing the sedimentary pile at the centre of the studied area with all main horizons interpreted. Figure modified from Delmas et al., 2002.

8.3.2. General structuration of the sedimentary pile in the study area

After application of methodology presented before and delimitation of all horizons presented in the Figure 8-5, a general trend is observed through all horizon's maps. Two main structures are observed though the sedimentary pile which will name The Charmotte anticline and the Clos-Fontaine anticline.

The Charmotte anticline is visible in the south of the area and affects the complete sedimentary pile. This structure dip to the north and bends to the west. As shown on Figure 8-6 and Figure 8-7, Charmotte anticline is 4.5 Km large and it narrows to the north with a width of 2.5Km. From its apex to its end, anticline length is 7.5 Km. This structure has been explored in the past as proved by position of wells BIS-1 and IVY-1D. This important structure corresponds to the structural trap from the southern Charmotte oil reservoir exploited by Vermilion Energy. It will be studied in more detail to identify its potential as a structural trap for CO2 Storage.

The second structure, which we named Clos-Fontaine anticline, corresponds to the small anticline visible on the eastern part of the time maps from Top_Oxfordian-Low to Top_Rhetian. This small structure has a N45°E direction with a deepening to the East-Northeast. This small structure affects only the lower portion of the sedimentary pile, which comprise the studied reservoir complex. Its width is comprised between 1.1Km and 0.5Km and its length ranges between 3 and 4 Km. On seismic data, a fault is observed at the edge of this structure which mostly impacts Triassic.

Computation of units' thickness map indicates a general trend for all units. Most of them present an important isopaceous trend with small thickness variation all along the seismic survey; this feature can be observed as well along seismic line with which displays no thickness variations. This calculation is consistent with the absence of significant seismic unconformities or structural elements, confirming the mild tectonic activity in this area.

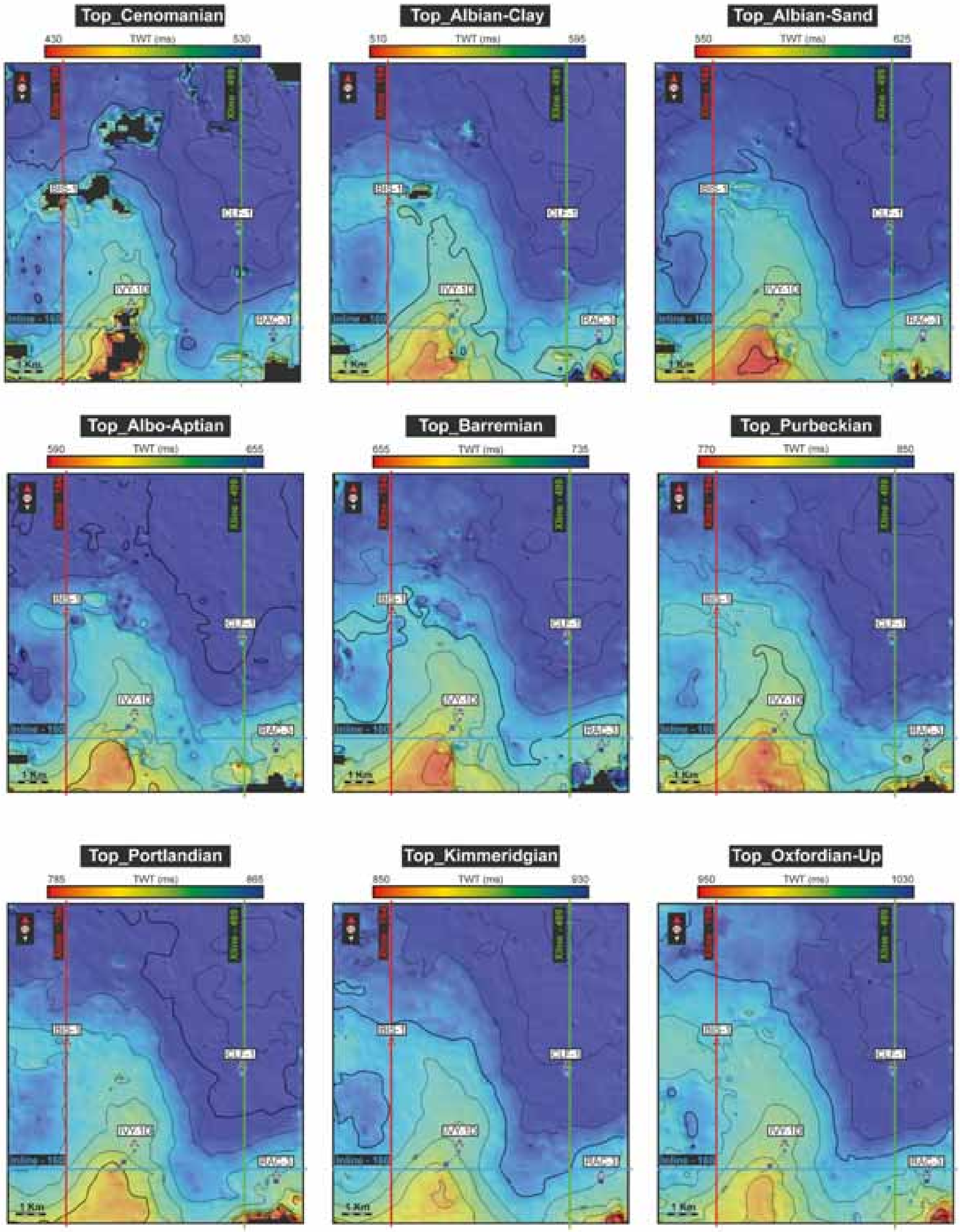

Figure 8-6 : Time depth map of horizons dividing the sedimentary pile of the studied area. Horizons from Top_Cenomanian to Top_Oxfordian-Up

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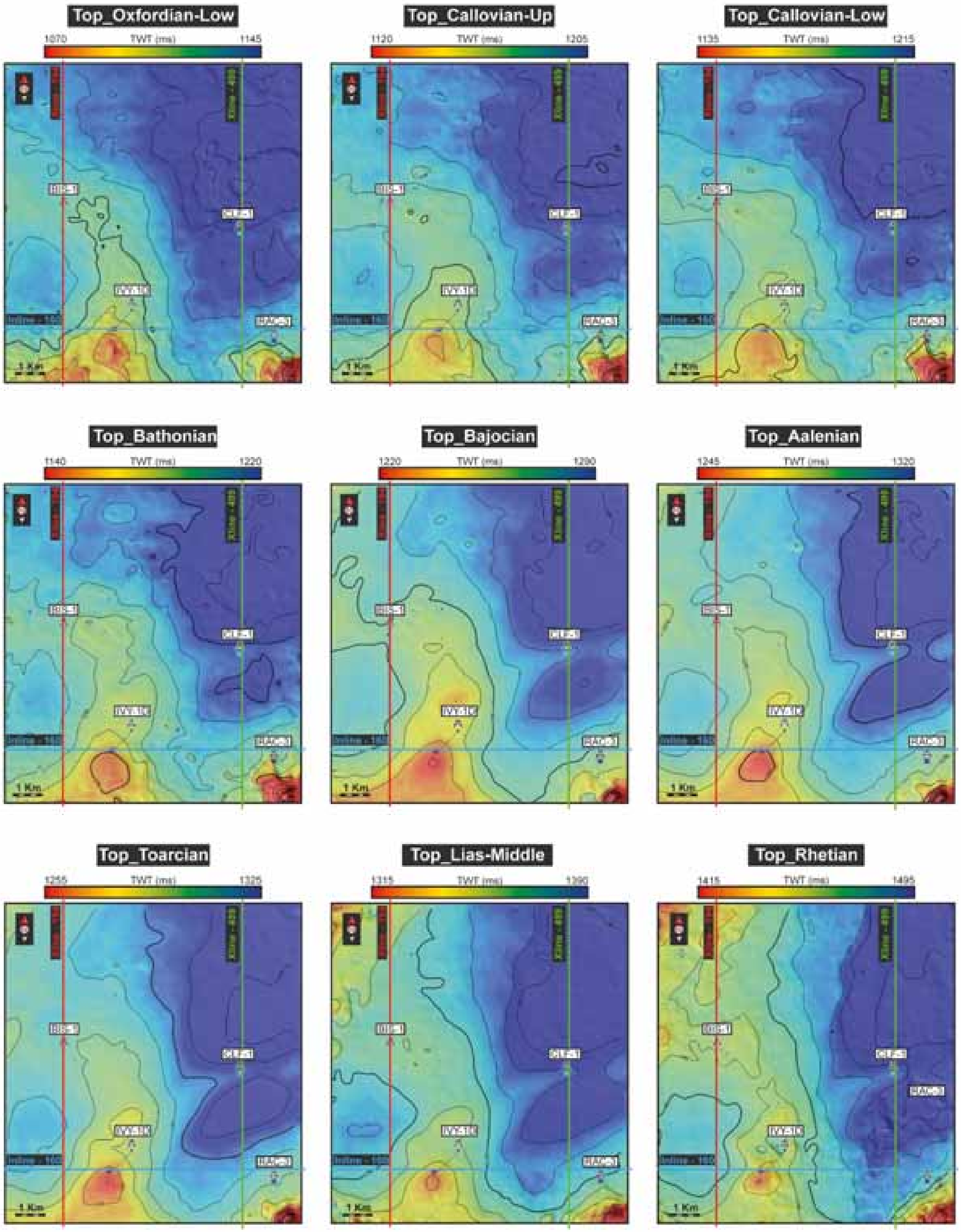

Figure 8-7: Time depth map of horizons dividing the sedimentary pile of the studied area. Horizons from Top_Oxfordian-Low to Top_Rhetian

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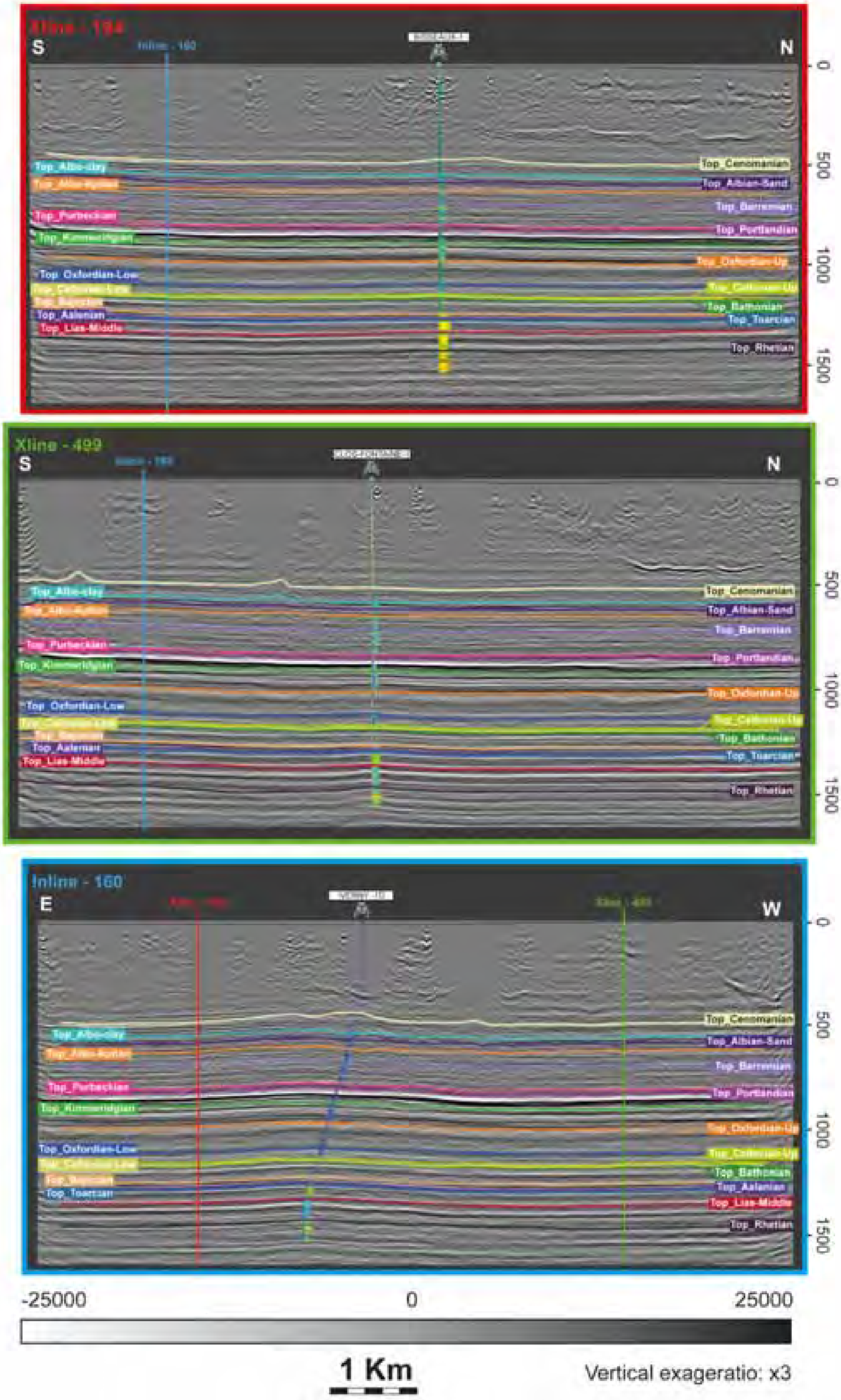

Figure 8-8: 2D slices of seismic cube at exploration wellbore location with interpreted stratigraphic horizons

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8.3.3. Specificity of the reservoir complex

As presented in section, the reservoir complex is bounded at the top by the horizon Top_Oxfordian-Up and the bottom by the horizon Top_Bajocian. All the stratigraphic intervals are affected by Charmotte and Clos-Fontaine anticlines, which creates *de facto* two structural-trap units.

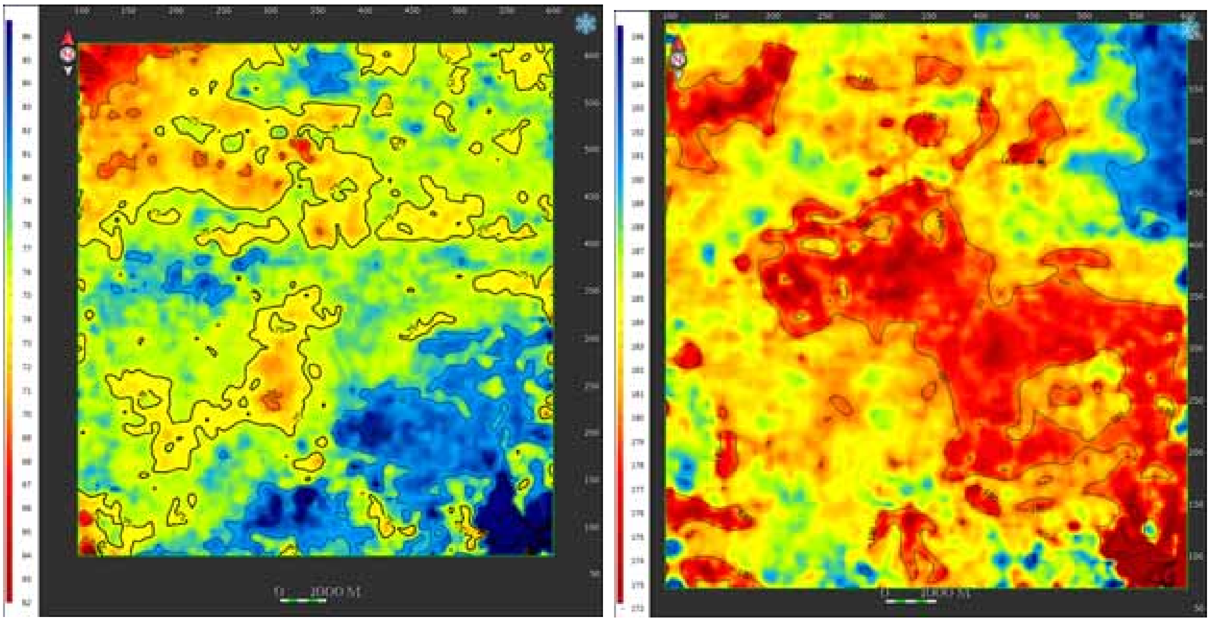

Figure 8-9: Thickness map in TWT (ms) of the reservoir section (a) and the caprock (b)

In detail, the reservoir interval does not present thickness variations and is characterized by a mean thickness of 77ms observed though the area (Figure 8-9). The Caprock, presents as well an isopachous geometry with a thickness varying between 172 and 196 ms. Analysis of specific Xline and Inline does not show amplitude variations which could reflect possible lithological variations. However, locally, some very weak toplap terminations could be interpreted suggesting a potential prograding wedge. But due to the preliminary nature of the processing data processing we prefer to keep our interpretation of an isopachous unit concerning the reservoir section until the final-processed data becomes available.

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A preliminary work has been started on seismic data attributes. Preliminary processing has been done with the objective of tracking some specific area with the best petrophysics properties associated to oobiolcastic grainstone, best reservoir facies. As such, spectral decomposition and a RMS. Amplitude extraction has been obtained. This processing allows to conduct a raw analysis as a first approach to provides a rough idea of the best suitable reservoir areas. It need to be compared with proper well data. These results will be presented in the deliverable 2.7. The Figure 8-10 presents these processing. The envelope and RMS Amplitude processing indicates two general trends. First one follows the apex and trend of the Charmotte Anticline. The second trend is observed at the North Central part of the seismic data with a trend from East to West. Unfortunately, the lack of well calibration concerning this specific interval does not let us to propose a specific interpretation related to the high reservoir potential of this area. However, specific work on well data compared with this specific processing will let us to propose a deep interpretation.

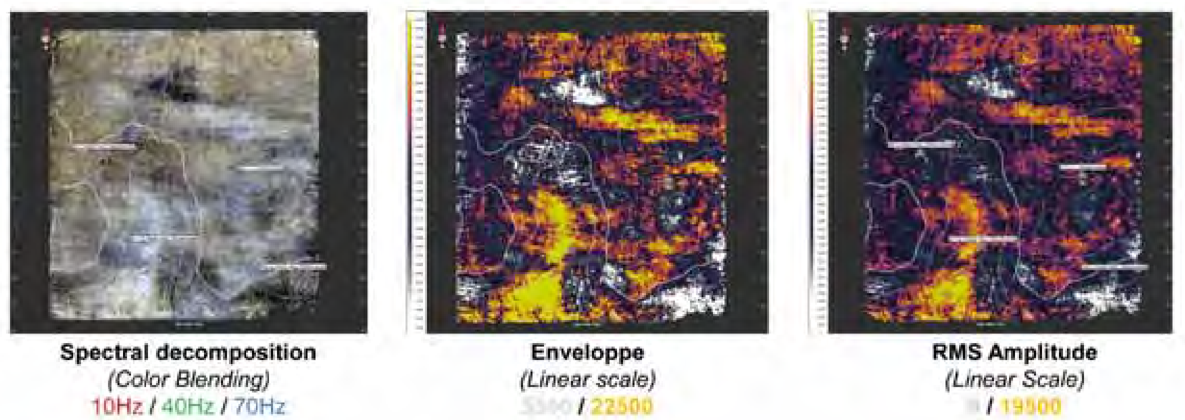

Figure 8-10: Spectral decomposition processing to highlight reservoir parameters

Finally, the spectral decomposition is generally used with the objective of detecting specific sedimentary geobodies. A potential channel has been detected in the Comblanchien Unit. This follows the conceptual geological model with potential tidal channel in the lagoonal facies of the Comblanchien Formation.

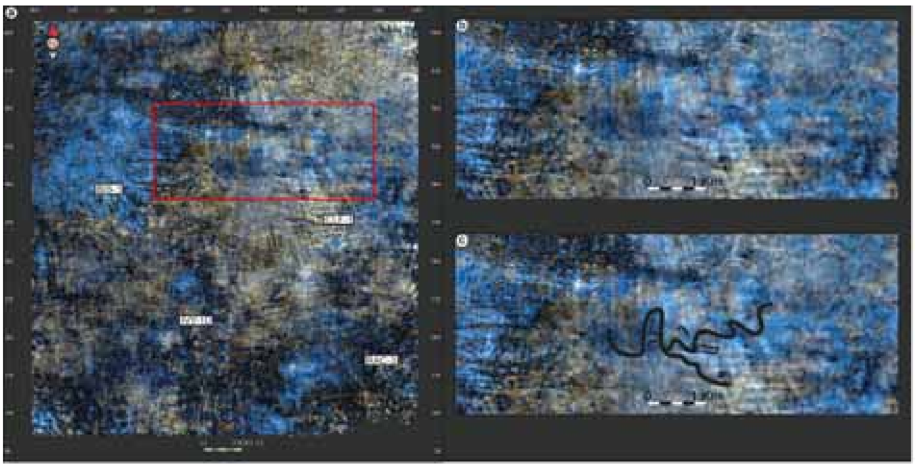

Figure 8-11: Color blended (RGB) spectral decomposition, with frequencies of 10Hz (Red), 40Hz (Green) and 70 Hz (Blue) showing channel shape in the Comblanchien Formation (lagoonal Facies).

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9. Conclusion

Design, permitting, acquisition, quality control and pre-processing of the campaign were carried out by Smart Seismic Solutions (S^3), third party partner of the project, from December 2021 to July 2022. The acquisition itself (layout of the receiver, vibration, collection of the receiver) took place over a period of only 5 weeks from mid-May until the end of June.

Despite difficulties accessing certain areas due to the refusal of some landowners and one town, the acquisition has been successful, and our activities were welcomed by most farmers and communities.

The entire experienced SMART SEISMIC SOLUTIONS team and the quality of the equipment involved, all in a spirit of agility, were the key to the success of this seismic operation carried out in 2 weeks, without incidents, in a particularly sensitive area to new industrial projects.

Our added value was decisive in the preparatory phase to better adapt the pre-planning to the permitting constraints.

It should also be noted that the exchange between geophysicists from BRGM and S^3 also contributes to the completion of this work. The images show reflections up to 2 seconds on raw recordings which is proof of the correct choice of parameters.

Despite a high rate of production and deployment/recovery of sensors, the entire team was able to reduce the nuisance and impact on the local population. SMART SEISMIC SOLUTIONS is proud to have been able to meet the challenge represented by this geophysical task, having left the region with a calm and favourable social climate following the operations carried out with our partner, the BRGM.

The preliminary interpretation of the seismic data along the full sedimentary pile indicates the high potential of this specific data for reservoir understanding in objective to CO2 storage. Computation of units' thickness map indicates a general trend for all units. Most of them present an important isopaceous trend with small thickness variation all along the seismic survey; this feature can be observed as well along seismic line with which displays no thickness variations. This calculation is consistent with the absence of significant seismic unconformities or structural elements, confirming the mild tectonic activity in this area. In detail, the reservoir interval does not present thickness variations and is characterized by an average thickness of 77ms. The Caprock, presents as well an isopachous geometry with a thickness varying between 172 and 196 ms.

A detailed work on other data as thin section, cores, well logs, and well log / seismic attributes comparison will let us to have a better understanding of the reservoir complex and propose a precise interpretation of the targeted reservoir.

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