WP2 – Deliverable 2.7 Geological Models Annex: Paris Basin – Grandpuits France

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1. Document History

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1.2 Revision History

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2. Introduction

This document aims to provide a summary and guidelines to complete the deliverable 2.7 of the PilotSTRATEGY Project.

The **deliverable 2.7** corresponds to the Work Package 2 (Geocharacterization) of **task 2.3** -Conceptual Geological Models-. It should materialize the **sub task 2.3.2** whose objective is "to develop the geological models for the 3 areas of study; Geological model based on facies analysis from available cores and cuttings, field analogues, log analysis, surface data and depositional environments, integrated with seismic stratigraphic and structural interpretations where available".

For each site, this document should provide the main petrophysical and facies analysis data for the development of the Static Model (WP3, task 3.1) and for the simulation of CO2 injection, including dynamic storage capacity (task 3.3). Therefore, this document must incorporate the results obtained from other tasks such as Task 2.3.1 Report on petrophysical measurements for reservoir and caprocks.

Detailed examination of facies has been conducted on cores and cuttings where available and/or field analogues. The stratigraphic sections available must have been logged in detail focusing on lithology, texture, allochem content in case of carbonate rocks, sorting, granulometry, mineralogy and sedimentary structures. Facies are determined and classified depending on their **depositional environments.**

Where feasible, seismic profiles from the study area, well log data, and outcrop sections must have been interpreted from a sequence stratigraphy perspective to establish stratigraphic cross-sections that allow an understanding of the spatial distribution of facies and their depositional geometry. Finally, the facies are linked to porosity and permeability variability within the reservoir and seal.

To provide context to the facies realisation, a structural framework showing major faults and thickness variations must be incorporated to the predicted lateral facies variations. The spatial distribution of faults and fracture networks must be a key input for the geological conceptual model.

To clarify the scope of this report, it is important to note that the geomechanical laboratory analysis and geochemical assessment performed in the tasks 2.4 and 2.5 are also of paramount importance for the modelling tasks of the WP3 but they are out of the scope of this deliverable 2.7. Regarding the hydrogeological system, although it may have aspects in common to the facies distribution of this deliverable, it will also be explained in a particular deliverable 2.11.

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3. Dataset per region

Paris basin has been during a long period a preferential target for oil and gas exploration (). Nowadays a large amount of data is available and usable for reservoir complex characterisation. These data image at different scale the reservoir complex from its general architecture with seismic data (2D / 3D) to facies reservoir scale with well logs, cores, thin sections and petrophysiques measurement. For an efficient analyse of these data, the study area is divided into two specific zone. First one correspond to the extension of the 3D seismic area and is related to the prospected area. Second one is associated to an extended area of interest. The latter will be implemented in the static model with bigger cell size in objective to understand injection influence out of the prospected area. Map presented below (Figure 3-1) indicate the position of all data used in this project and extension of different areas.

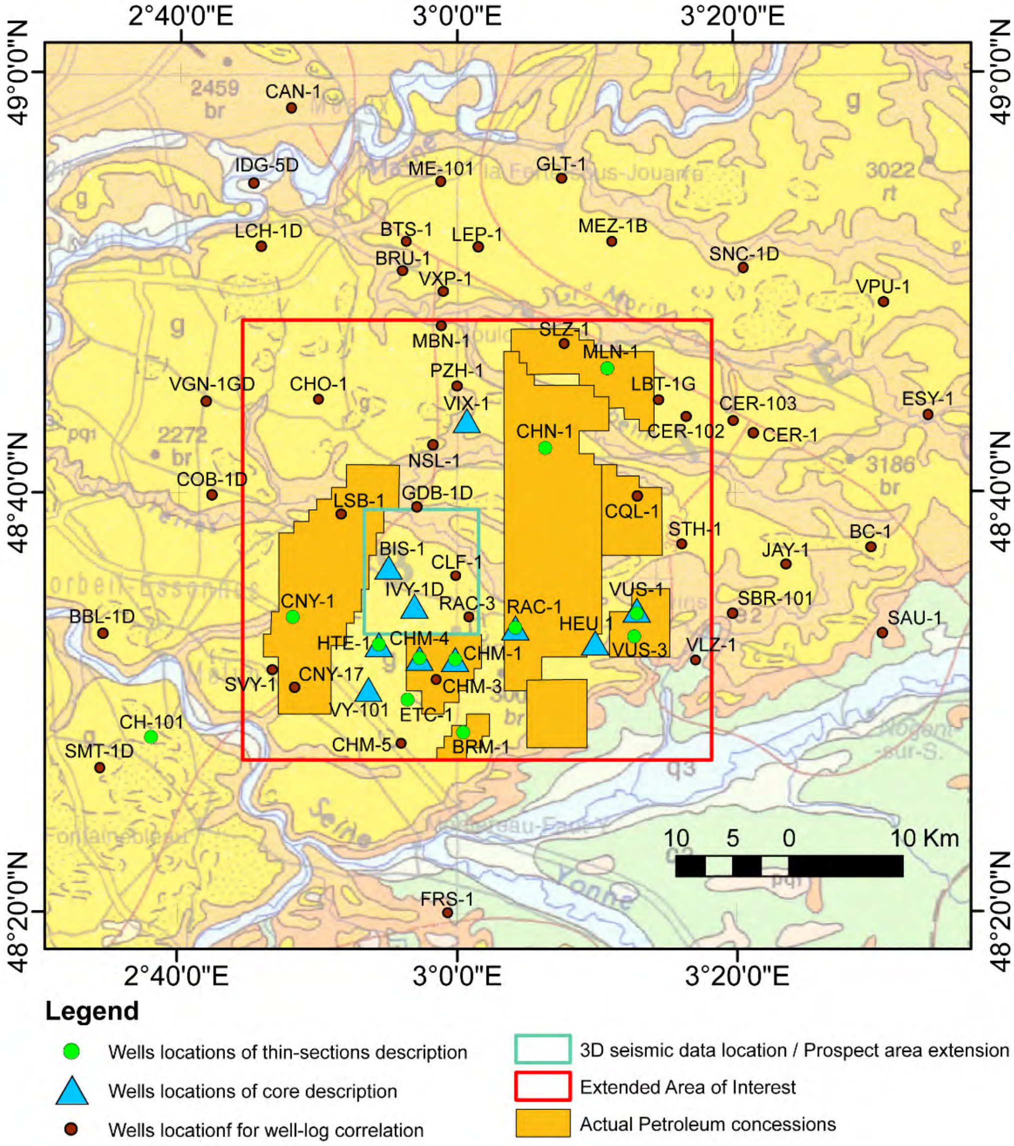

Figure 3-1: Location map of dataset used in the French region.

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3.1 Seismic data

Newly acquired for the project, a 3D seismic cube has been used for the reservoir complex architecture characterisation. Detail concerning this data acquisition, processing and QA/QC has been presented in the Deliverable 2.3. Seismic interpretation proposed here has been conduction on PSTM seismic cube processed by CDP Consulting Company. Detail of the processed seismic data characteristics are resumes in the table below. This table resume the different units (vertical vs horizontal), data limits (X, Y, and Z), and resolution of the seismic data.

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 m^2
In-line Min	58	Seismic cube name :	
In-line Max	634		CCUS3D_PSTMstack_postproc

Figure 3-2: 3D seismic data characteristics used for PilotSTRATEGY Project.

3.2 Well data

3.2.1 Well data in the extended AOI

In this study, 46 wells are used in objective to characterise large-scale reservoir complex geometry, depositional environment interpretation and electrofacies / facies variations along the area. Data quality from these well are different, depending their ages and purpose of the drilling well. After a QA/QC on well data, 42 wells has been selected in the extended AOI. These wells have basics well logs measurements as Sonic (us/ft) ; GR (API) ; Neutron porosity (v/v) ; Bulk density (g/cm3) ; Resistivity medium (Ohm/m) ; Resistivity Depp (Ohm/m) and Spontaneous potential (mV). Locations of these wells are presented in the Figure 3-1. Details of each wells characteristics and available data are presented in Annexe I.

3.2.2 Well data in the prospect area

In the seismic area, 4 wells from oil exploration are present and use to conduct seismic interpretation and facies calibration. Well location and their deviation are presented in the Figure 3-3. Detailed of the well data are presented in the table below. Only one well has a checkshot calibration and propose a velocity law. This allow the team to propose a precise seismic / well tie and an accuracy picking of the horizons.

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Well Name (ID)	Coordinate	TD / TVD	Interval Cored	Logs	Velocity Low
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

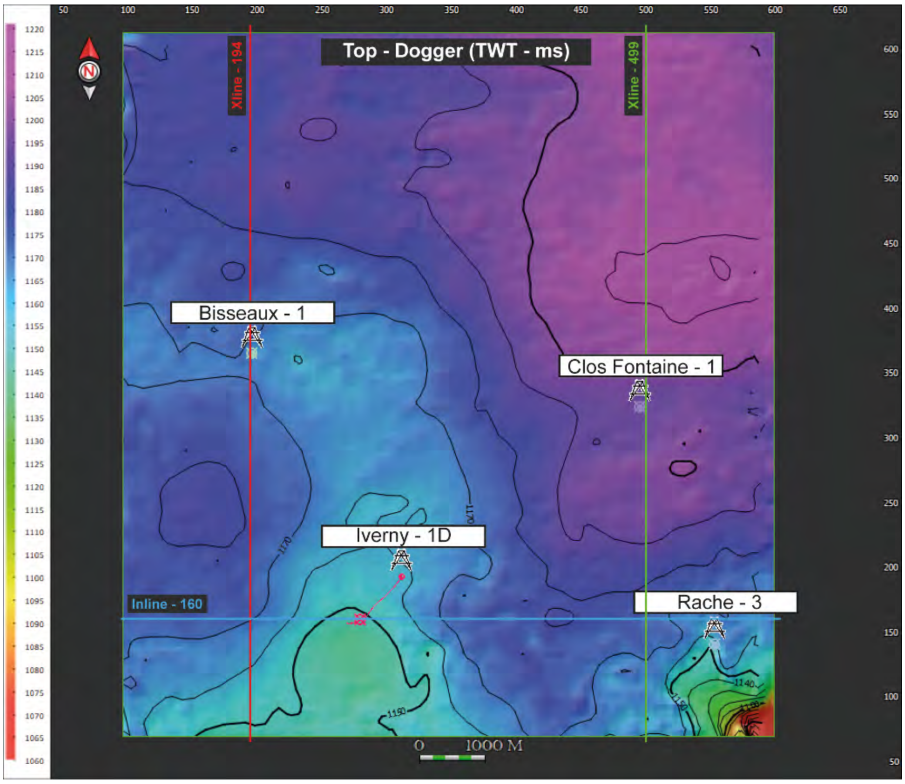

Figure 3-3: Well's location and their path in the prospected area. Extension of the area is presented in Figure 3-1.

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Then, thanks to previous study done by BRGM on Paris Basin specific petrophysics logs has been processed on the well CLF-1, IVY-1D and RAC-3. In the detail, processed logs proposed correspond to:

- Total and effective porosity,
- Oil, gas and water saturation,
- Shale volume from Gamma ray and Density Neutron,
- Reservoir flag,
- Mineralogical volume (Calcite, Dolomite, Illite, Quartz, Kaolinite, Anhydrite)

However, no specific reports mention these data. It do not let us to have a critical review and QA/QC revision of the latter. Consequently, presentation and use of these specific data have to be taken with precautions.

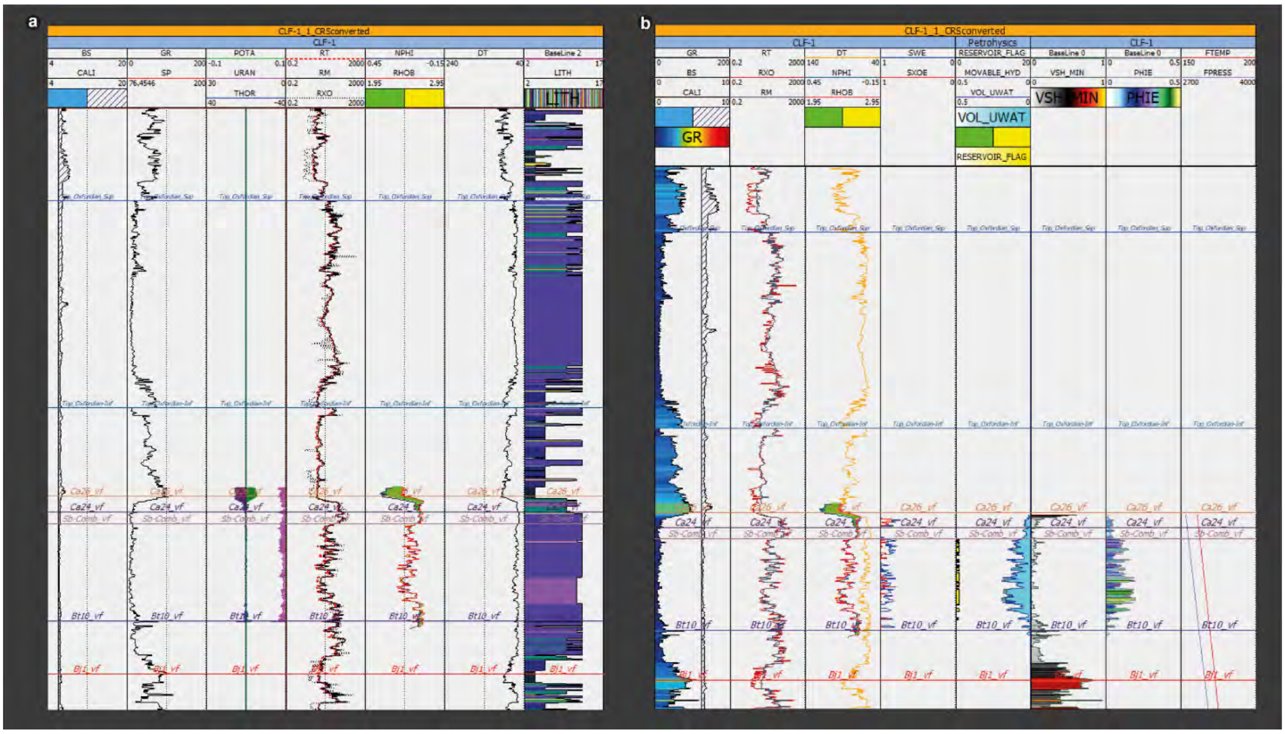

Figure 3-4: Well logs exemple for a) acquired well logs and b) processed logs

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3.3 Core data

Thanks to the presence of many oil exploration wells in the area, it has been possible to observed and describe sedimentary cores. These cores correspond to the top of the reservoir section that is not the main target. Indeed, top of the reservoir targeted correspond locally to an oil display as in the Charmotte field, located at the south of the extended AOI. Figure 3-1 give an example of core location compare to the reservoir section.

Cores have been selected with two criteria's. First criteria correspond to its geographical location, inside or close to the prospect area. Then, other cores has been selected because of their depth and how much they sampled the Reservoir-1, which is the proper target for CO_2 storage.

Consequently 372 meters of cores has been describe in this study (Tableau 3-1). Sedimentological description has been conducted at scale 1/50 and because reservoir section correspond to an oolitic carbonate ramp, Dunham classification has been used. Attention has been taken on sedimentary structures, porosity (qualitative description), main diagenetic features (stylolites, fractures…), and elements (Oolithe, macroscopic fauna, bioclast…). A specific attention has been taken on diageneses and elements distribution (Oolithe vs Bioclast). Indeed, these parameters influence drastically reservoir properties (porosity, permeability) for oolitic ramp prospect. Example of sedimentological core description is presented in Figure 3-5

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Tableau 3-1: Details of core described in the PilotSTRATEGY Project

Well Name	Area	Cored interval	Recovery	Complex reservoir sections
BISSEAUX-1	Prospect	1837-1879m 2 Cores 42 meters	100%	Base Caprock1 Reservoir2 Semi-Permeable 1
CHARMOTTES-4	Extended AOI	1790-1826m 2 Cores 36 meters	98%	Reservoir2 Semi-Permeable1 1 Top Reservoir 1
CHARMOTTES-1	Out of AOI	1786.4-1830.2m 5 Cores 43.8 meters	100%	Base Caprock1 Reservoir2 Semi-Permeable1
HEURTAULT-1	Extended AOI	1862-1907 3 Cores 45 meters	100 %	Reservoir2 Semi-Permeable1 1 Top Reservoir 1
HEURTEBISE-1	Extended AOI	1769-1800m 2 Cores 31 meters	100%	Base Caprock1 Reservoir2 Semi-Permeable 1
IVERNY-1D	Prospect	2082-2116m 3 Cores 34 meters	83%	Reservoir2 Semi-Permeable1 1 Top Reservoir 1
RACHEE-1	Extended AOI	1837-1879m 3 Cores 42 meters	100%	Base Caprock1 Reservoir2 Semi-Permeable1
VILLARCEAUX-1	Extended AOI	1900-1930 2 Cores 30 meters	100%	Base Caprock1 Reservoir2 Semi-Permeable1
VILLEFERMOY-101	Extended AOI	1776-1816 5 Cores 40 meters	78%	Base Caprock1 Reservoir2 Semi-Permeable1 1 Top Reservoir 1
VULAINES-1	Out of AOI	1840-1919 6 cores 79 meters	55%	Base Caprock1 Reservoir2 Semi-Permeable1 1 Top Reservoir 1

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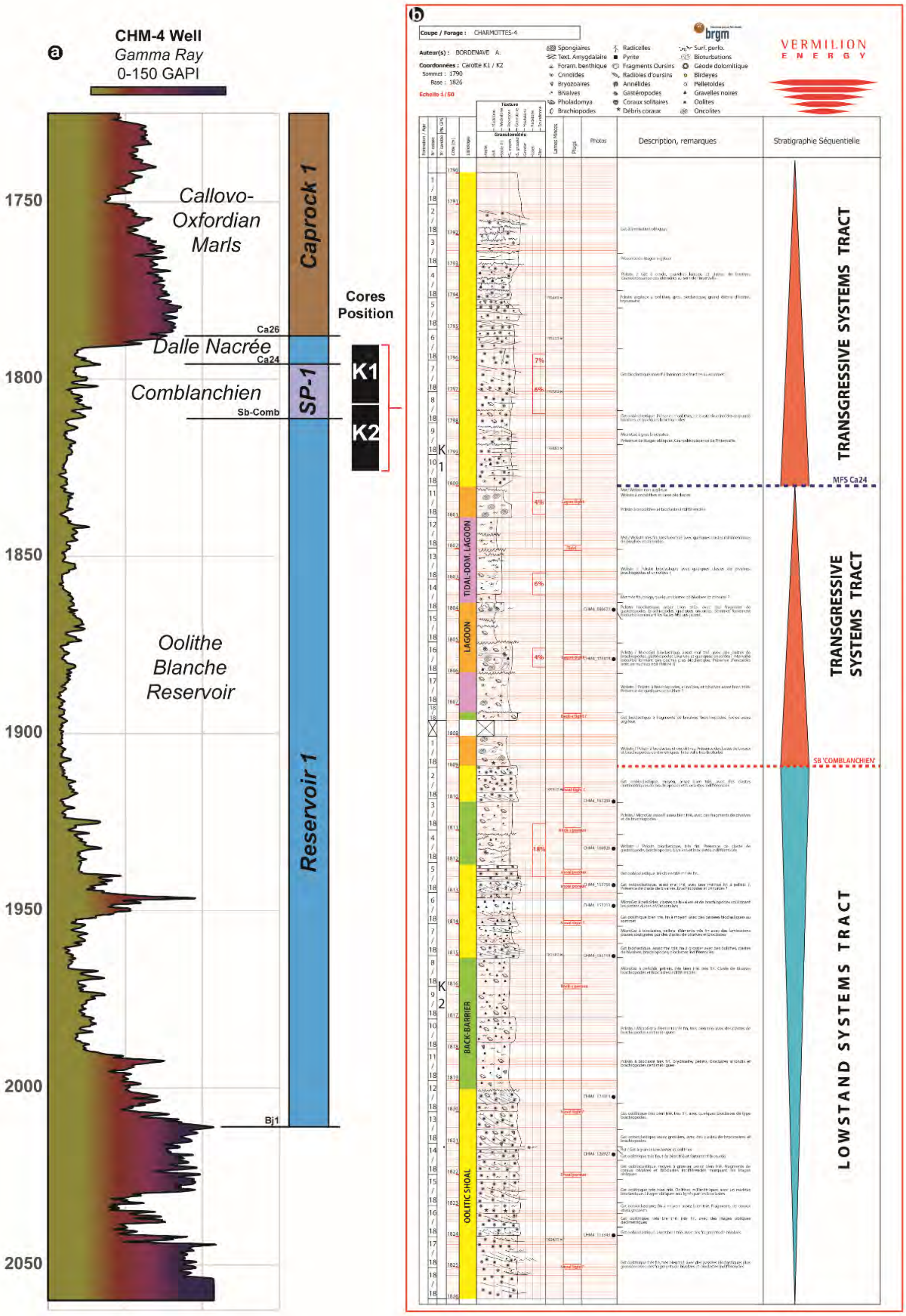

Figure 3-5: Example of (a) reservoir representation of cored intervals and (b) sedimentological core description

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3.4 Thin-sections

During oil and gas explorations in the area, companies conducted sampling and analysis on plugs from cores. Thanks to these data, a microfacies analysis has been conducted on some cores (described and furthermore). Cores from RACHEE-1, VULAINES-1 and HEURTEBISE have been sampled and 107 thin sections has been described. Features presented below has been identify and details are proposed in Annexe:

- Non-skeletal grains (ooids, oncoids, extraclast…)
- Skeletal grain (bryozoan, echinid, algea…)
- Texture from Dunham classification, grain sorting,
- Diagenetic features (type of ciment, dolomite, fractures…)
- General comment

Then, for each element identified, a relative quantification is proposed following methodology proposed by IODP (Method 371), following the Technique of Rothwell (1989). Elements relative abundance could be define as Dominant (>50%), Abundant (>25%-50%), Common (>10%-25%), Rare (1%-10%), Trace (<1%).compared though all the thin section.

Finally, in objective to understand porosity distribution and connectivity, further thin section description has been conducted of other samples from undescribed cores which are all located in the area of interest. A total of 164 thin sections has been described on cores samples from 9 wells. Location of these cores are presented in Figure 3-1.

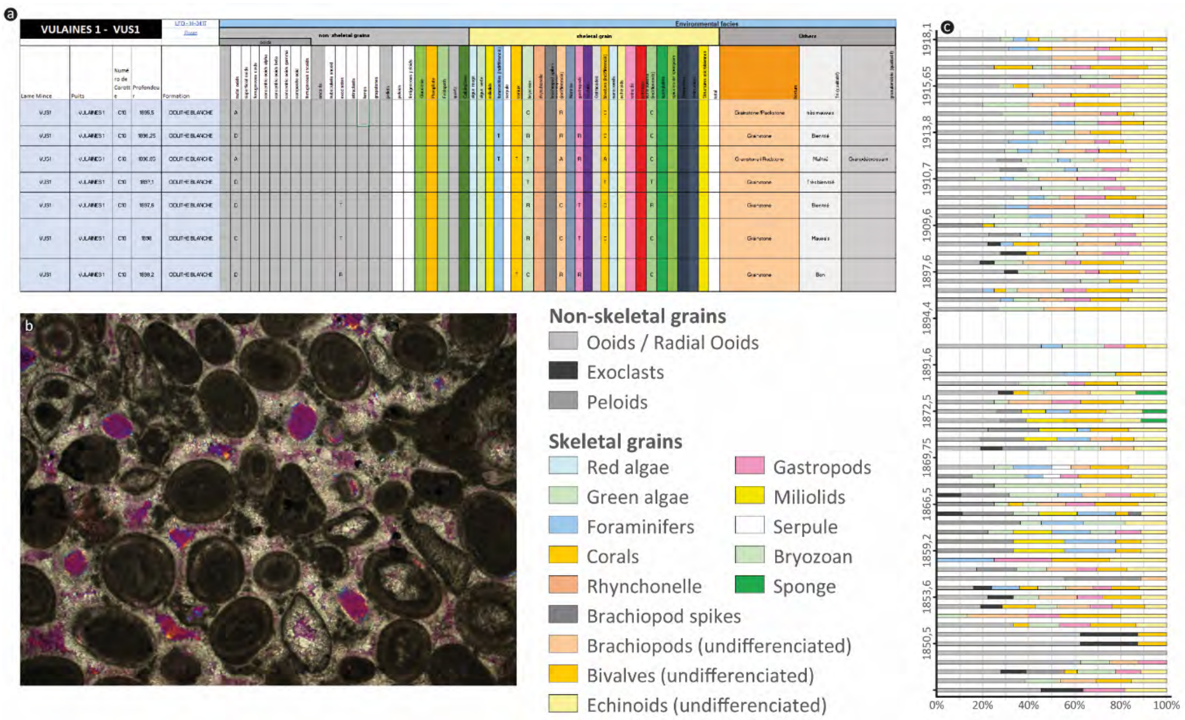

Figure 3-6: Exemple of thin-section study along samples from Vulaines-1 well. a) spreadsheet example of thin-section qualitative analyse; b) Thin-section photo showing an oolitic grainstone ; c) Quantitative representation of non-skeletal and skeletal grain composing Vulaines-1 facies.

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4. Regional Geological Characterization

4.1 The Paris Basin: its structuration and tectono-stratigraphic history

The Mesozoic / Cenozoic Paris Basin correspond to an intracratonic sedimentary basin, with a sag geometry, lying unconformably over a Paleozoic basement (bibliography). The tectono-sedimentary evolution of this basin is mainly influenced by regional geodynamical events associated to extensive stages as the Mesozoic opening of the Alpine Tethys, Atlantic Ocean and Bay of Biscay, and compressive event as Late Cretaceous-Cenozoic Pyrenean and Alpine orogenies. This long-term geological evolution let the onset of eleven major tectono-sedimentary cycles from the Triassic to the Tertiary. These cycles are detailed in Figure 4-1. In the specificity of PilotSTRATEGY project, the reservoir complex is associated to the transgressive stage of the Lower Bathonian – Oxfordian cycle. This interval correspond to the onset of the Dogger Platform (Middle Jurassic).

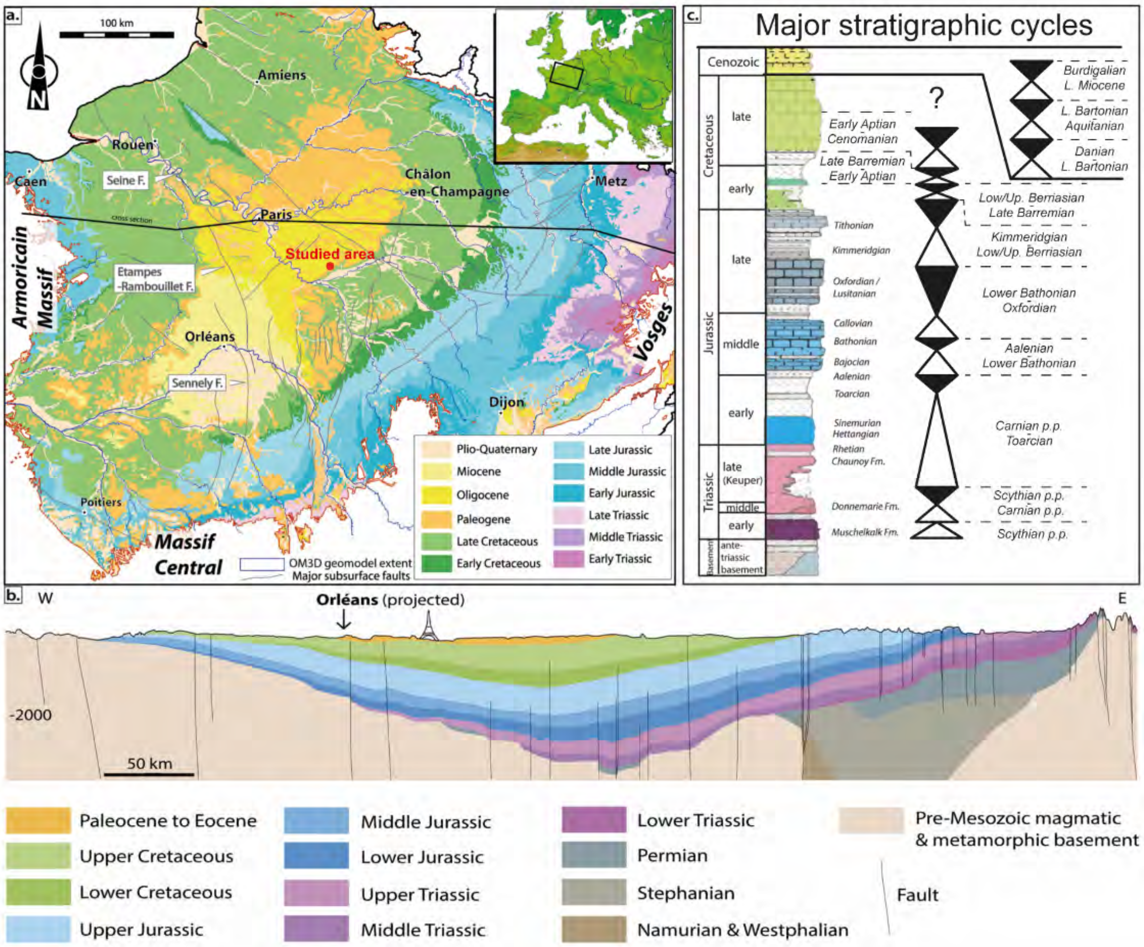

Figure 4-1: a) Geological map of the Paris basin and location of the geological section. c) Mains sequence stratigraphic cycles of the Paris Basin, proposed by Guillocheau et al., 2000. Mas et al., 2022

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4.1.1 Basement structuration

The tectono-stratigraphic evolution of the Paris basin is genetically linked and influenced by the Variscan mountain belt paleogeography and its main structural architecture (fault and thrust). Resulting from the carboniferous collision between the Avolania and Gondwana plates and the closure of the RHEIC Ocean, the Variscan basement is divided into4 domains, which are themselves divided into different structural blocks (Figure 4-2). These domains are bounded by major tectonic accidents (faults and/or thrust). These domains corresponds to:

- **The Armorican domain:** divided into 8 blocks (Cadomian, North Armorican, Central Armorican, Ligerian, Mauges Nappes, Evry-Tonnerre, AMBP, North Vosges) this bloc is essentially located in the eastern part of the basin and bounded by the Seine fault, followed by the Rambouillet and Loire Fault to the south.
- **The North Gondwana margin:** Located at the southern part of the basin, this domain is divided in to two blocs with the Movan-Vosges Bloc at the South-East and the Aigurande domain in the south.
- **The Rheno-Hercyninan domain:** present in the northern part of the Paris Basin, this domain is composed of one bloc also called Ardennes-Pays de Bray block. The latter is bounded in the south by the Bray fault and in the east by the Metz fault.
- **The Saxo-Thuringian bloc:** Baptiste (2016) proposed a continuity of this bloc from the eastern part of the Paris Basin to the west with the succession from east to the west of the Sare, Seine, and Manche blocks. This succession is bounded in the north by the Bray and Metz fault system and in the south by the Sare and Seine fault system with the junction of the Evry fault in the center of the basin.

Figure 4-2: Synthesis of structural framework of Paris basin Basement a) Structural scheme of the Variscan chain zonation from Baptiste., 2016. b) Interpretative structural scheme and geological zonation of pre-Mesozoic basement of the Paris Basin. Figure from Baptiste., 2016. c) Structural map at the Top of the Dogger platform. Figure from Delmas et al., 2002. d) Line drawings of the 4 main regional sections which bound the studied area. The main faults and calibration-wells are shown: SMBF: Saint-Martin-de-Bossenay fault; ERF: Etampes-Rambouillet fault; BVF: Bray-Vittel fault. For the N–S lines, the South is at the left; For the E–W lines, the West is at the left

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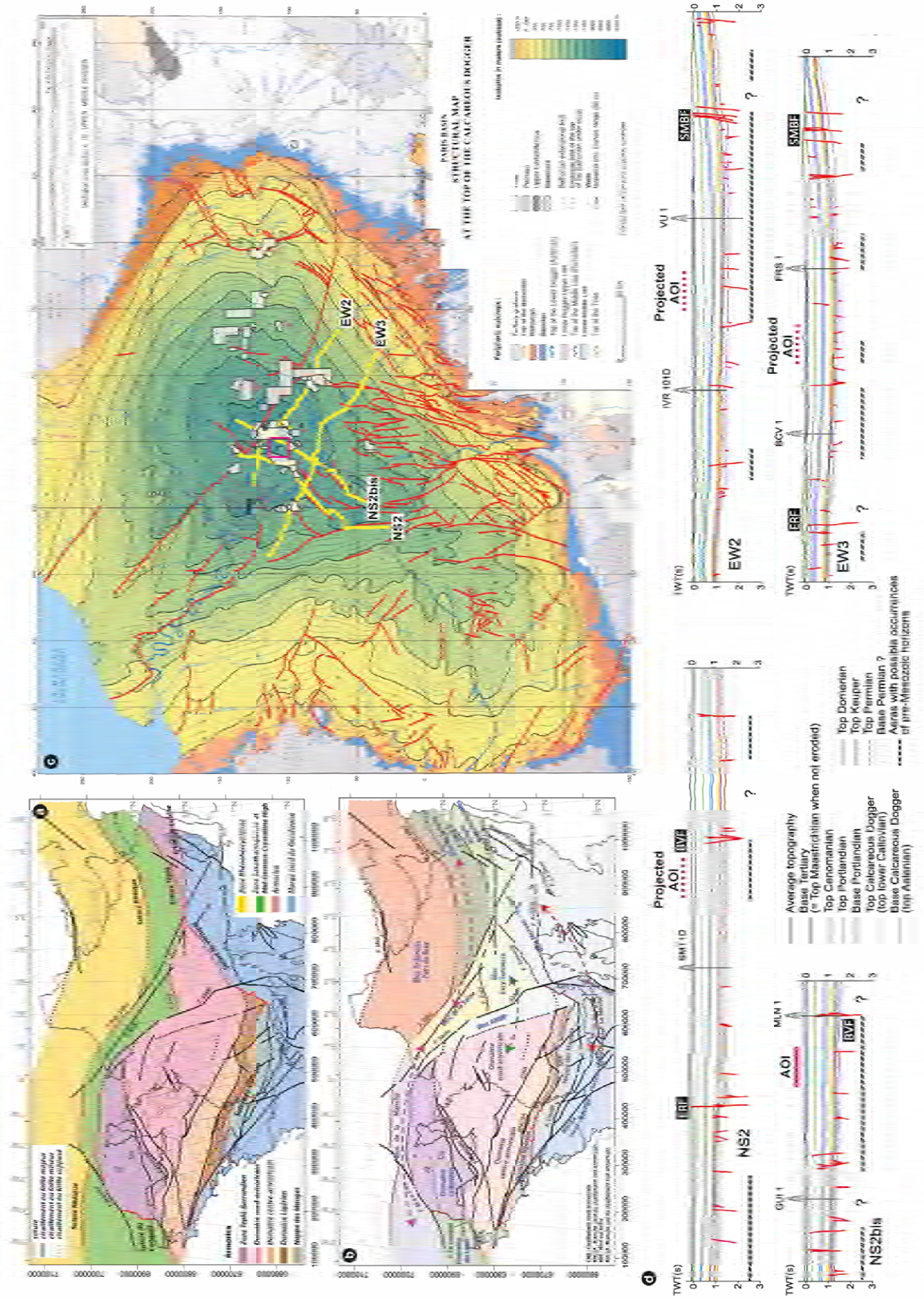

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4.1.2 Tectono-stratigraphic evolution of the Paris Basin:

After the strong compressive event, resulting to the formation of the Variscan mountain belt, the Paris basin stayed far away to strong tectonic activity and its sedimentary tectono-sedimentary evolution has been influenced to far field deformation from regional major geodynamical events affecting the western European plate (Pyrenean, Alpine orogenies, Atlantic opening...). These events induced local variscan fault reactivation and slight deformation with initiation of gentle folding and occasionally fault inversion. Five main stages, related to regional geodynamical events are proposed by Guillocheau et al., 2000 and resumed in the Figure 4-3:

- **The Late Permian-Toarcian stage**, which correspond to an extensive regime, is associated to regional permo-triasic rifting event. Two main subsidence directions are recorded with an E-W and NNE-SSW one.
- **The Aalenian-Tithonian stage** record as well an extensive regime with the activity of syn-sedimentary fault system, which decrease during the upper Jurassic. The followed subsidence regime change with a NW-SE flexural trend control. During this stage, subsidence is widely record with an equal distribution during Kimmeridgian –Tithonian (Guillocheau et al., 2000). It's proposed that this subsidence is associated to the separation between Laurasia and West Gondwana and the beginning of oceanic accretion of the Ligurian Tethys. This event induce as well the post-thermal subsidence of margins.
- **The Berriasian-Aptian stage** marked a net decrease of the subsidence and a drastic change in the sedimentation (from Jurassic carbonate deposits to siliciclastic). Inception of detrital sedimentation is associated to the uplift of western Europe, linked to the rifting and oceanic accretion of the Bay of Biscay. Consequently, first tectonic inversion are recorded in the southern part of the basin with the inversion of Variscan fault and the record of hundred meters scale vertical movement and erosion in the Artois region.
- **The Albian-Late Turonian stage** is highlighted by a change in the sedimentation from the siliciclastic deposits to calcareous deposits with the onset of widespread carbonate platform associated to chalk sedimentation. This variation in the sedimentation is associated to a moderate tectonic activity linked to E-W extension during the Cenomanian and local N-S compression in the Boulonnais. In the same time, the oceanic accretion is recorded in the Bay of Biscay.
- **Late Turonian-recent stage** is commonly associated to a general compressive tectonic setting with a far field deformation related to the Pyrenean and Alpine geodynamical events. During the Late Turonian to Campanian, a long wavelength deformation is recorded in the Paris Basin. The compression stage increase during the Campanian-Maastrichtian with a general N-S compressive regime, which induce a re-activation of variscan structures as the inversion of Bray and Somme faults. This compression is directly linked to geodynamical reorganisation with the beginning of the Pyrenean cycle. Then a second major compressive phase is recorded in the basin from, still linked to Pyrenean phase and induce fault reactivation (Etampes and Rambouillets faults) and short wavelength foldings. This compressional phase is followed by local extensive regime, mainly observed in the eastern side of the Basin. This extension is associated to the opening of the Bress and Rhine graben from Eocene to Oligocene. Finally, a last major compressive regime occurred in the Late Miocene with the NW-SE compressional regime. This last major compressive event, dated between Upper Oligocene to Pliocene is linked to the compression of the Jura Mountain.

Nowaday, the Paris Basin correspond to an uplifted area as proposed Robin et al., 2003.

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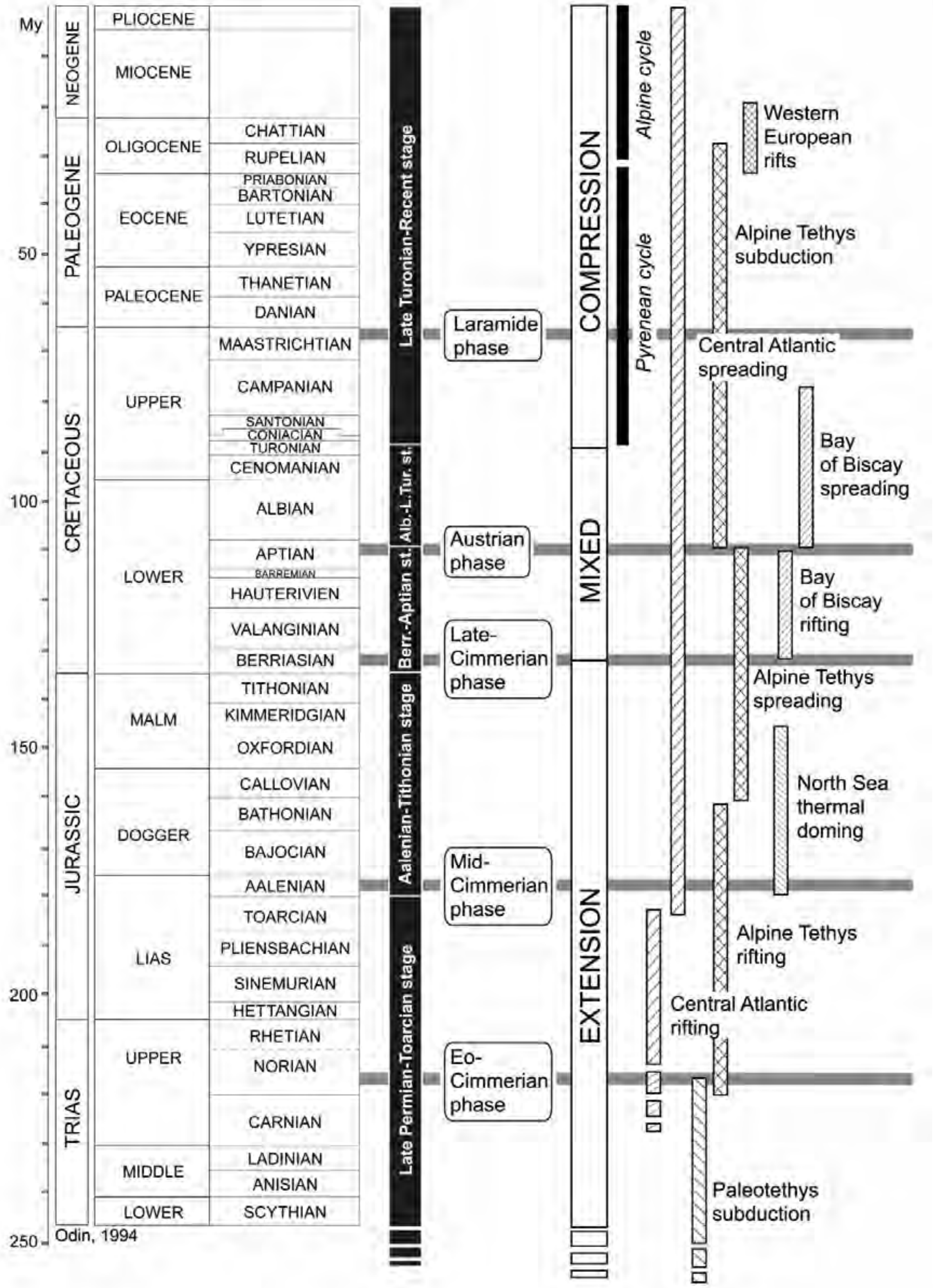

Figure 4-3: Main stages of the tectono-sedimentary evolution of the Paris Basin, separated by their major unconformities (grey horizontal strokes), with the corresponding tectonic phases. The major related regional geodynamic events, compiled from Guillocheau et al. (2000) and Stampfli and Borel (2002).

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4.1.3 The Dogger Ramp – Regional reservoir

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, the Atlantic to the southwest. However, the later was less well connected to northern oceans because of the exposed London-Brabant and Armorican massifs (Figure 4-4).

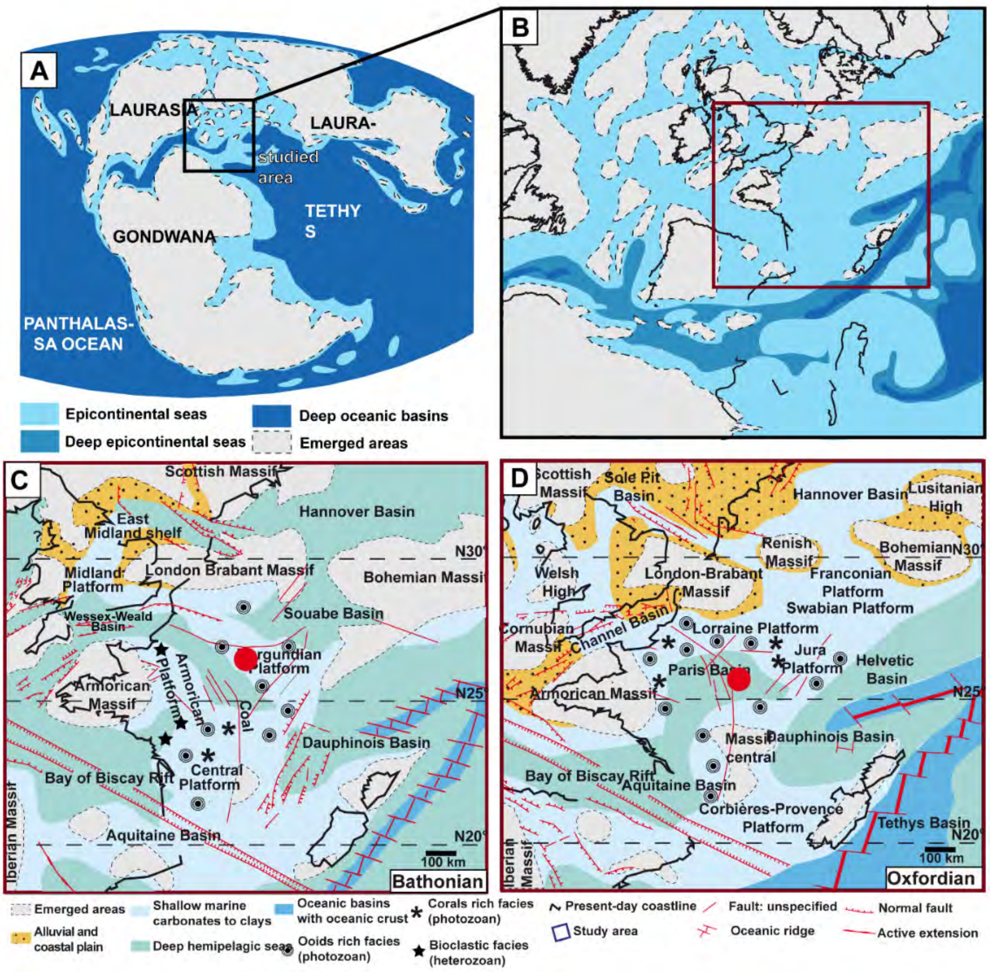

Figure 4-4: D. Location of the study area during the Oxfordian in a paleogeographic reconstruction (modified from Strasser et al., 2015; based on Enay and Mangold, 1980; Ziegler, 1988; Thierry and Barrier, 2000). Figure modified from Andrieu et al., 2016.

After the early to late Bajocian carbonate crisis, deposition of open-marine marls 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. 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, resumed which will be detailed in the next chapter.

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4.2 Sedimentological and Structural context review of the Dogger platform in the AOI

4.2.1 Structural review

The area of interest is located in the northern part of the Evry-Tonnerre Block, close to the connection between the Evry and the Seine Fault (Figure 4-2). Main structural mapping data provided from the bibliography and interpretation of the 3D seismic data indicate the absence or non-visible structural accident from the existing data (Figure 4-2).

Mappings provided by Baptistes 2016, correspond to the interpretation of magnetic anomaly, which could be associate to structural accident affecting basement. Following this interpretation, the restricted area of interest (3D seismic data emprise) is bounded by two anomalies in the south and north. Compared with the Structural map at the top of the Calcareous Dogger (reservoir), provided by Delmas et al., 2002, these anomalies are not associated to potential fault, which would cross the reservoir section (Figure 4-2). Finally, analyse of the 3D seismic data give us a final image of the structural framework of the restricted area. Seismic interpretation indicate the presence of a potential fault, with a N60°E trend, sealed by Triassic sediments.

In the extended area of interest, 8 faults will be integrated in the static model These faults are interpreted and retrieval from Delmas et al., 2002. As shown on Figure 4-5, directions of these faults are associated to general trends observed in the Paris Basin. General mapping and shifting are visible in the Figure 4-5.

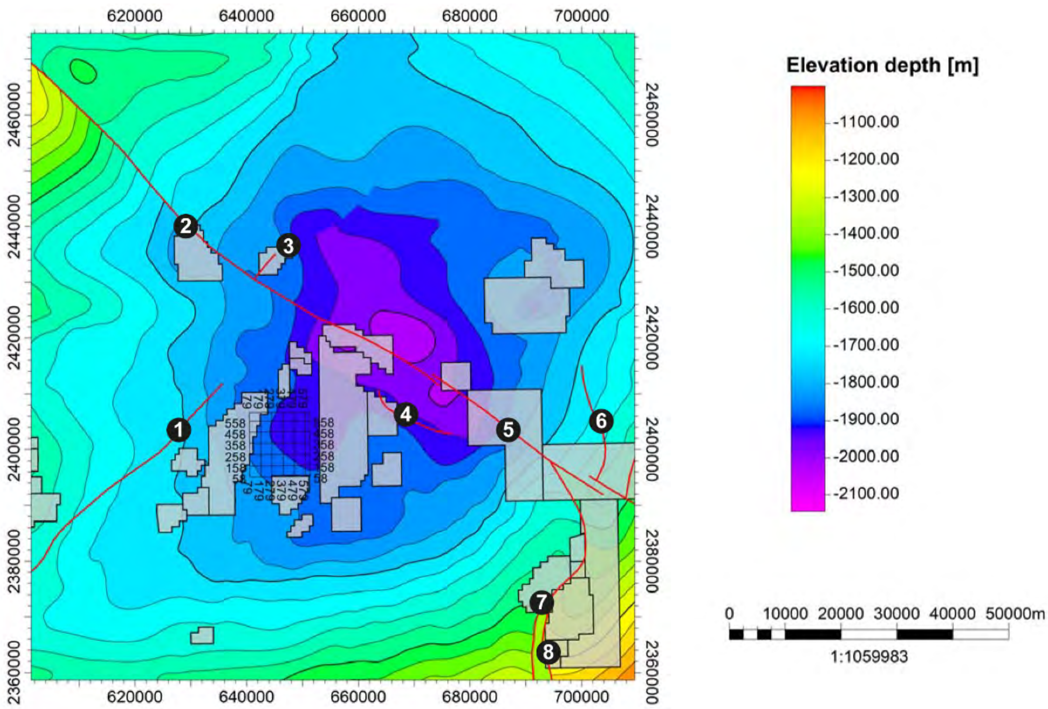

Figure 4-5: Maps showing main structural accident integrated in the static model of the extended AOI. Base map corresponds to depth map of the Bt10 horizon, interpolated from well log markers.

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4.2.2 Sedimentological characteristic of the Dogger in the AOI

Core description conducted to the definition of 37 sedimentological facies, regrouped into 17 facies associations which define seven depositional environments. All facies are related to the same general sedimentary system associated to the development of a low angle oolitic ramp. Facies description are not presented here because of the high number of facies described on sedimentary cores. All of them are grouped into 16 facies associations resumed in the figure below and detailed in the Annexe 2. These facies association, thanks to, their texture, mineralogy, fauna distribution and sedimentological structures let us to define seven depositional environment which correspond, from distal to proximal, to i) Upper offshore; ii) Lower offshore ; iii) Outer ramp; iv) Shoal ; v) Back-shoal; vi) tide-dominated lagoon; and vii) lagoon. These depositional environments are briefly described below.

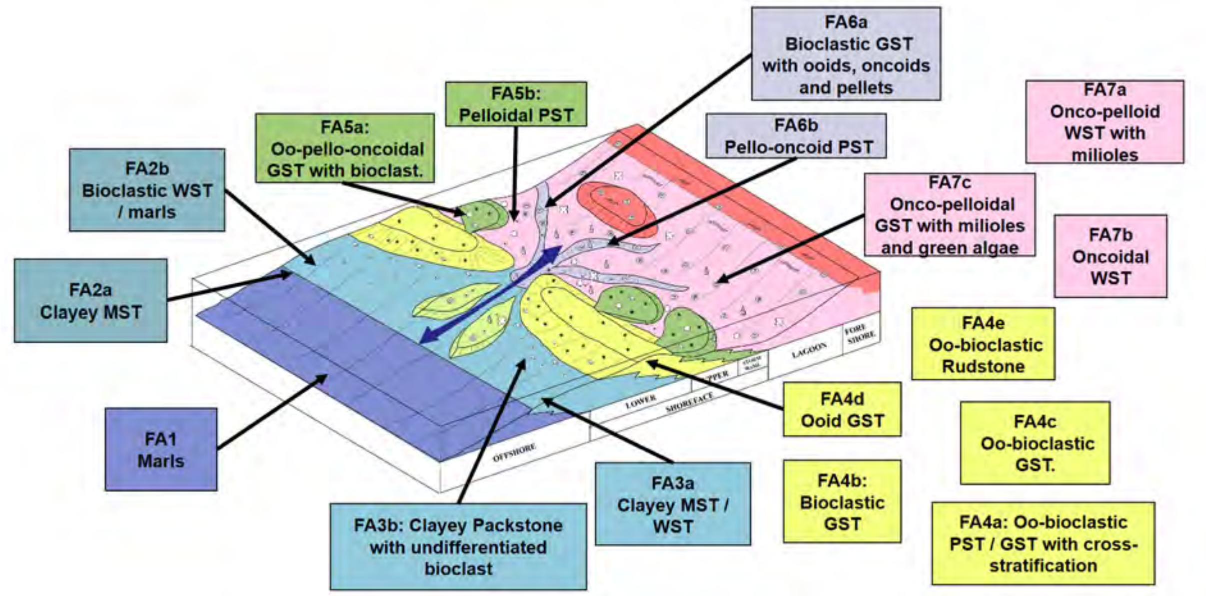

Figure 4-6: Facies association distribution along the depositional model of the oolitic ramp, characterising the reservoir of the Dogger storage complex

Compared with well logs data and general knowledge of the area, lateral facies variation are weak compare to vertical facies variations. Consequently, vertical facies distribution define the lithostratigraphic framework of the Dogger platform in the studied area. Five lithostratigraphic formation compose the Dogger platform. In stratigraphic order, these formations correspond to:

- ***Marnes à Ostrea acuminata* Formation**. Associated to Bajocian age, these marls represent the deepest depositonal envionment identified in the study area (Upper offshore).

- ***Oolithe Blanche* Formation.** Linked to high-energy inner ramp depositional environment, this formation is mainly composed of grain-supported limestone (grainstone, packstone) with abundant ooids, pelloids and bioclastic debris from bivalves, echinoderms, bryozoans and gastropods. It compose the core of the targeted reservoir and represent outer ramp, shoal and bac-shoal depositional environments.

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- ***Calcaire du Comblanchien* Formation.** Mainly compose of oncoids packstone, wackstone and some mudstone, this formation indicate the onset of Lagoon environment. Top of this formation indicate the Maximum regressive surface of the Bajocian-Callovian cycle.
- ***Dalle Nacrée* Formation**. This last grainy formation is associated to the transgressive stage of the Callovian-Oxfordian cycle. It correspond to the deposition the early stages of a bioclastic isolated ramp that developed during the Early Callovian in the study area. As the Oolithe Blanche formation, main depositional environments are shoal and back-shoal deposits.
- ***Callovian marls* Formation**. Last lithostratigraphic formation associated to the Dogger platform, these marls are associated to offshore deposits (Upper and Lower) and seal the last calcareous facies formation.

Details concerning sequence stratigraphic framework of the Dogger platform and its relation and classification in the storage complex is detailed in the next chapter.

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4.3 Storage Stratigraphy

The storage complex is defined as the succession of the followed lithostratigraphic units (inverse to stratigraphic order):

1. Oxfordian Limestone (Caprock-2)
2. Callovo-Oxfordian Marls (Caprock-1)
3. Dalle Nacrée Formation (Reservoir-2)
4. Calcaire du Comblanchien Formation (Comblanchien) (Semi-Permable1)
5. Oolithe Blanche Formation (Reservoir-1)

The Oolithe Blanche Formation is associated to the onset of an oolitic ramp developed during the Aalenian-Toarcian stage, associated to a widespread tectonic subsidence / quiescence. Architecture of the reservoir is consequently associated to eustatic variations and the onset of Maximum Flooding Surfaces. Detailed sequence stratigraphic analysis has been realised in this study and based on the CLF-1 well, located in the seismic cube emprise. Hereby we propose a sequence stratigraphy framework at different scale with i) a second, ii) a third order and high frequency cycles. The detailed description is proposed in the annexe 3.

In objective to have the best ratio between an accurate complexity representation of the reservoir architecture and a best static model for dynamic calculation, we decided that the reservoir and seismic interpretation will be done at the third order scale. Figure 4-7 indicated names of horizons used for seismic data interpretation. In stratigraphic order this horizons correspond to

1. **Bj1** – Bottom of the storage complex
2. **Bt10** – Maximum Flooding Surface which divide prograding and aggrading reservoir stages
3. **Sb-Comb** – Sequence Boundary, which indicate vertical facies variation between HST and LST. It define as well the bottom of semi-permeable reservoir
4. **Ca24** – Maximum Regressive Surface of the Bajocian-Bathonian cycle. This horizon indicate the vertical facies variaiton between Comblanchien lagoonal facies (LST) and Dalle Nacrèe oolitic facies (TST)
5. **Ca26** – Non-associated to a specific sequence stratigraphic surface, this horizons indicate top of reservoir facies of the Dalle Nacrée formation (Reservoir 2)
6. **Top_Oxfordian_Lower** – Non-associated to a sequence boundary, this horizon define the vertical facies variation between Callovo-Oxfordian Marls and Oxfordian Limestone.
7. **Top_Oxfordian_Upper** – Maximum Regressive Surface of the Callovian-Oxfordian Cycle, This horizon define the top of the Caprock 2 and the storage complex.

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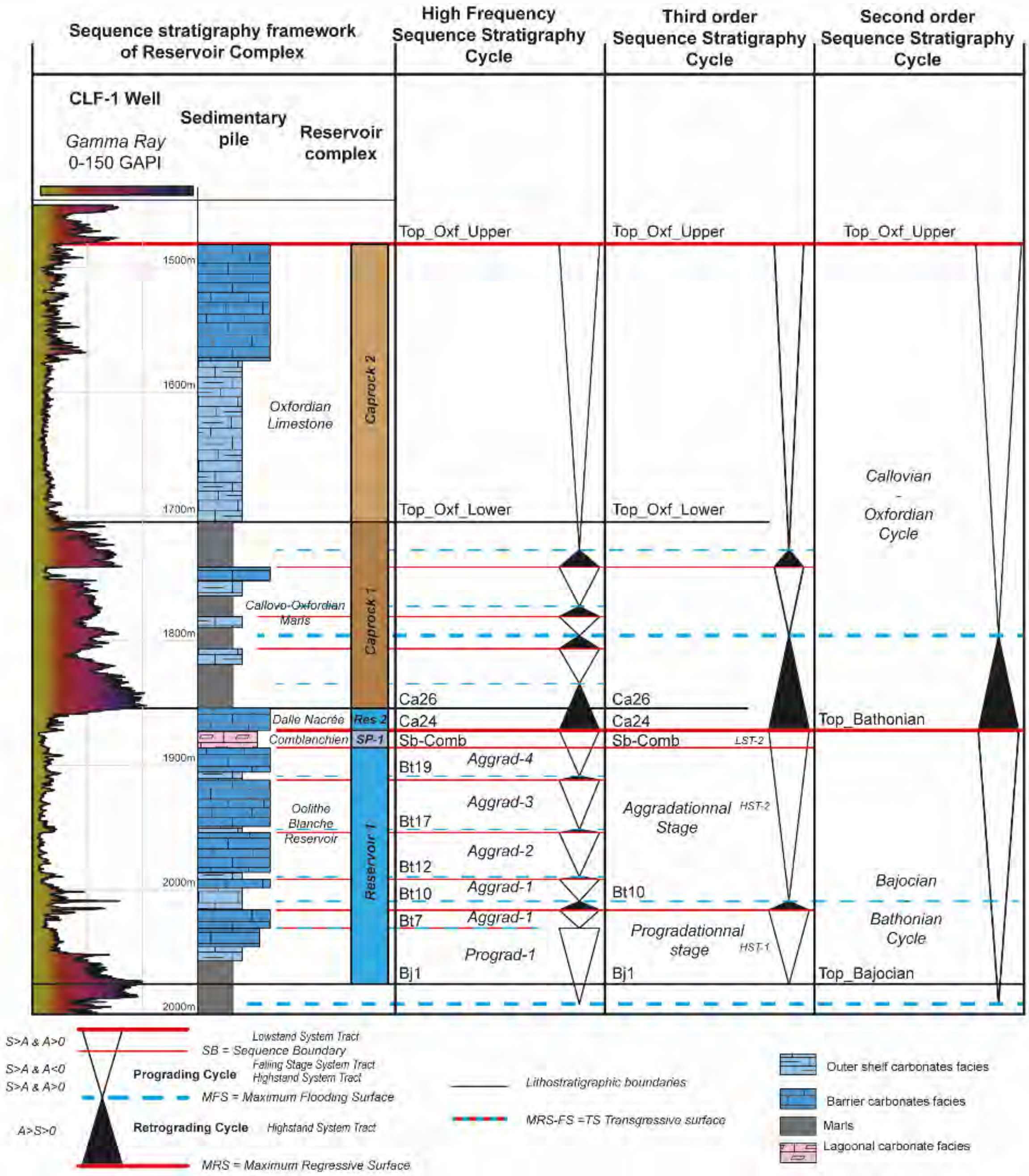

Figure 4-7: Sequence stratigraphic delimitation of the reservoir complex.

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5. Storage Complex Characterisation

5.1 Horizons and Faults interpretation in the area of interest.

5.1.1 Interpretation

Seismic interpretation has been conducted following methodology proposed in Annexe 4. Seven horizons has been interpreted. These horizons delimit six seismic units. Specificity of the studied area is the absence of major unconformities. Consequently, seismic interpretation is based on stratigraphic framework proposed along wells. In objective to propose a proper seismic unit framework, horizons followed markers interpreted along CLF-1 wel, unique well with a velocity law and checkshot. These units will be present from top to Bottom. Seismic interpretations examples, isohypse and isochore maps are respectively proposed in figures 7-2 to 7-5.

- **Unit I – Caprock 2 (Top_Oxf_Upper to Top_Oxf_Lower)**

This first seismic-unit correspond to the second unit defined as caprock (Figure 4-7). The unit is bounded by the horizons Top_Oxf_Upper at the top and the Top_Oxf_Lower horizons at the bottom. It do not present a strong thickness variation with an homogeneous thickness distribution between 106 and 128 ms. After a time / depth conversion, this thickness range correspond to 246 and 297 meters with a total volume estimation as 30 Km^3, and a projected surface as 110 Km^2. The unit do not present as well specific amplitudes variations. It is characterised by its important homogeneity and seismic facies could be characterised as tabular to slightly transparent. However, located at the northern part of the area, horizons geometry vary and potential clinoforms are identified (Figure 5-1). This specific structure is interpreted as a local reef platform development with the identification of reef plat and front domains. This interpretation follow as well bibliography, which indicate the development of this kind of platform during late Oxfordian (Andrieu, 201).

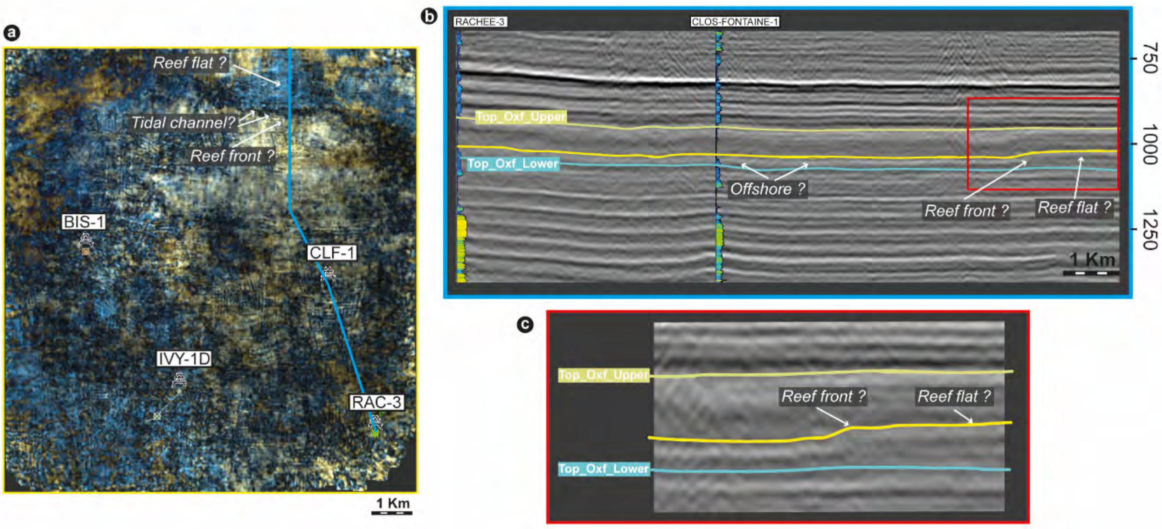

Figure 5-1: Interpretation of potential reef platform development at the northern part of the AOI. a. colour blended (RGB) spectral decomposition attribute maps of the yellow horizons shown on part b and c. b. Seismic line showing lateral seismic facies variation and lateral geometry variation of the horizon. c. close-up of the potential reef platform with interpretation of reef front and reef flat domains. Vertical scale is in Two Way Time (ms).

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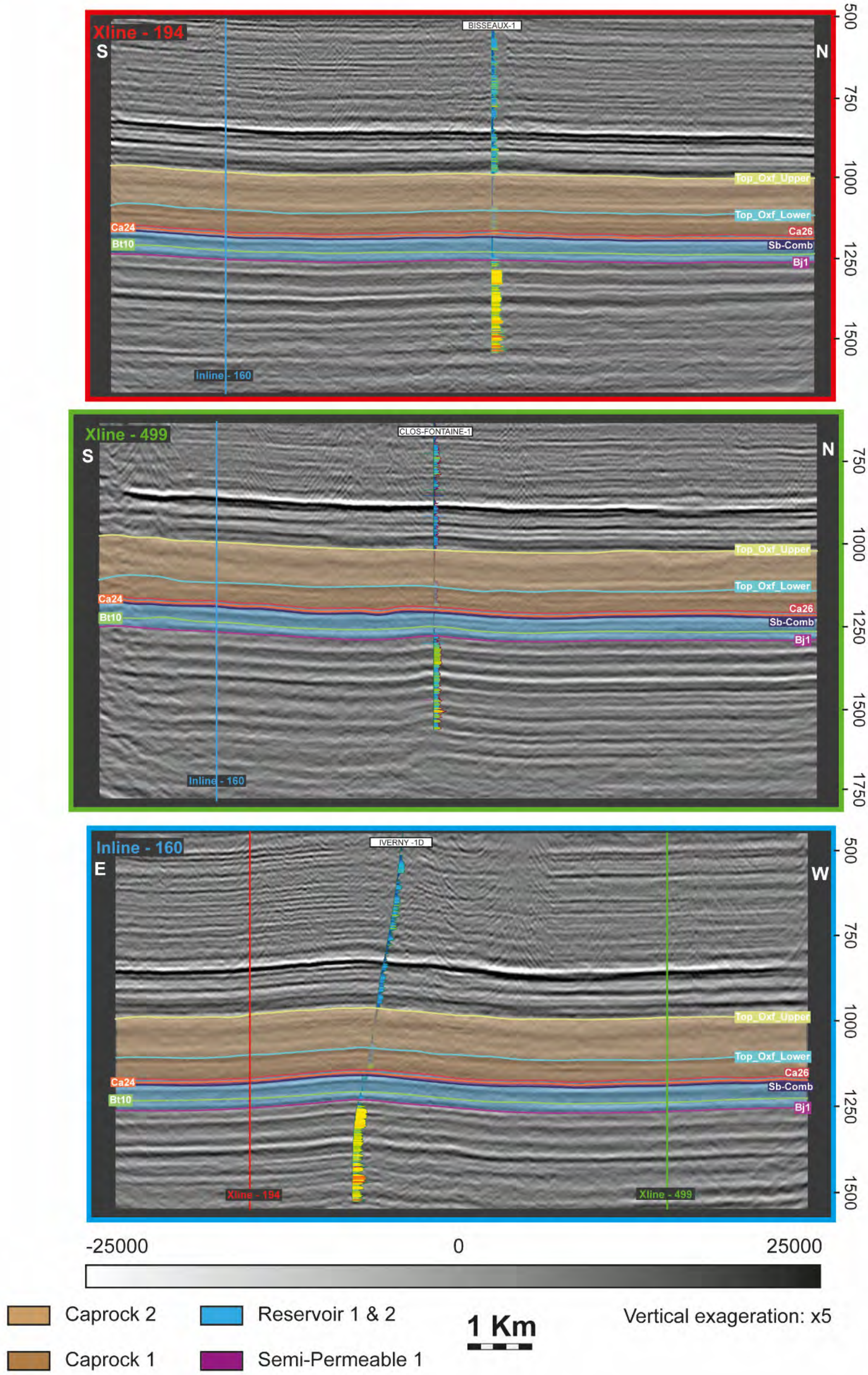

Figure 5-2: Seismic interpretation of storage complex horizons and distribution of Caprock and reservoir intervals along three seismic lines. Seismic lines locations are shown on figure 7-4. Vertical scale is in Two Way Time (ms)

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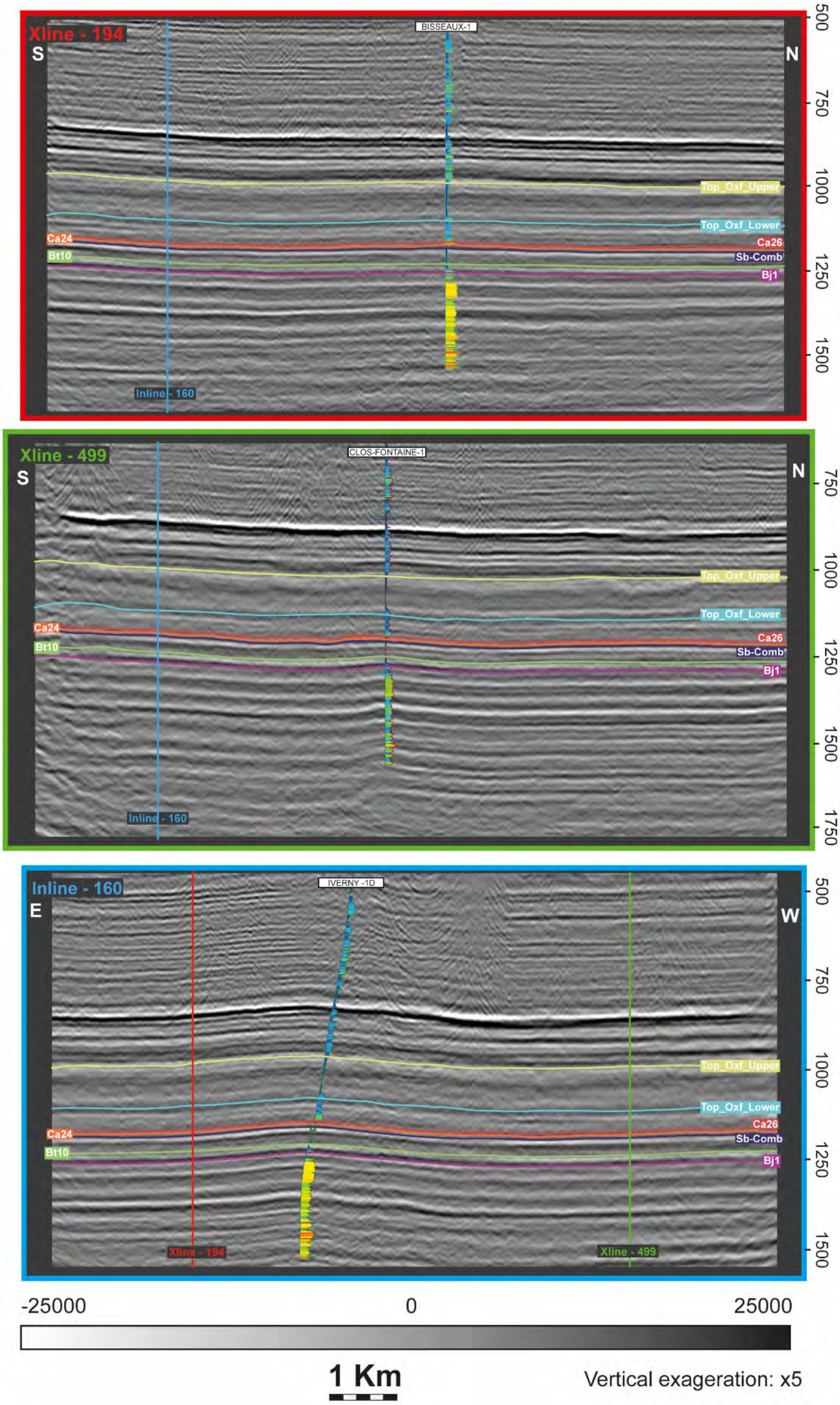

Figure 5-3: Seismic interpretation of storage complex horizons along three seismic lines. Seismic lines locations are shown on figure 7-4. Vertical scale is in Two Way Time (ms).

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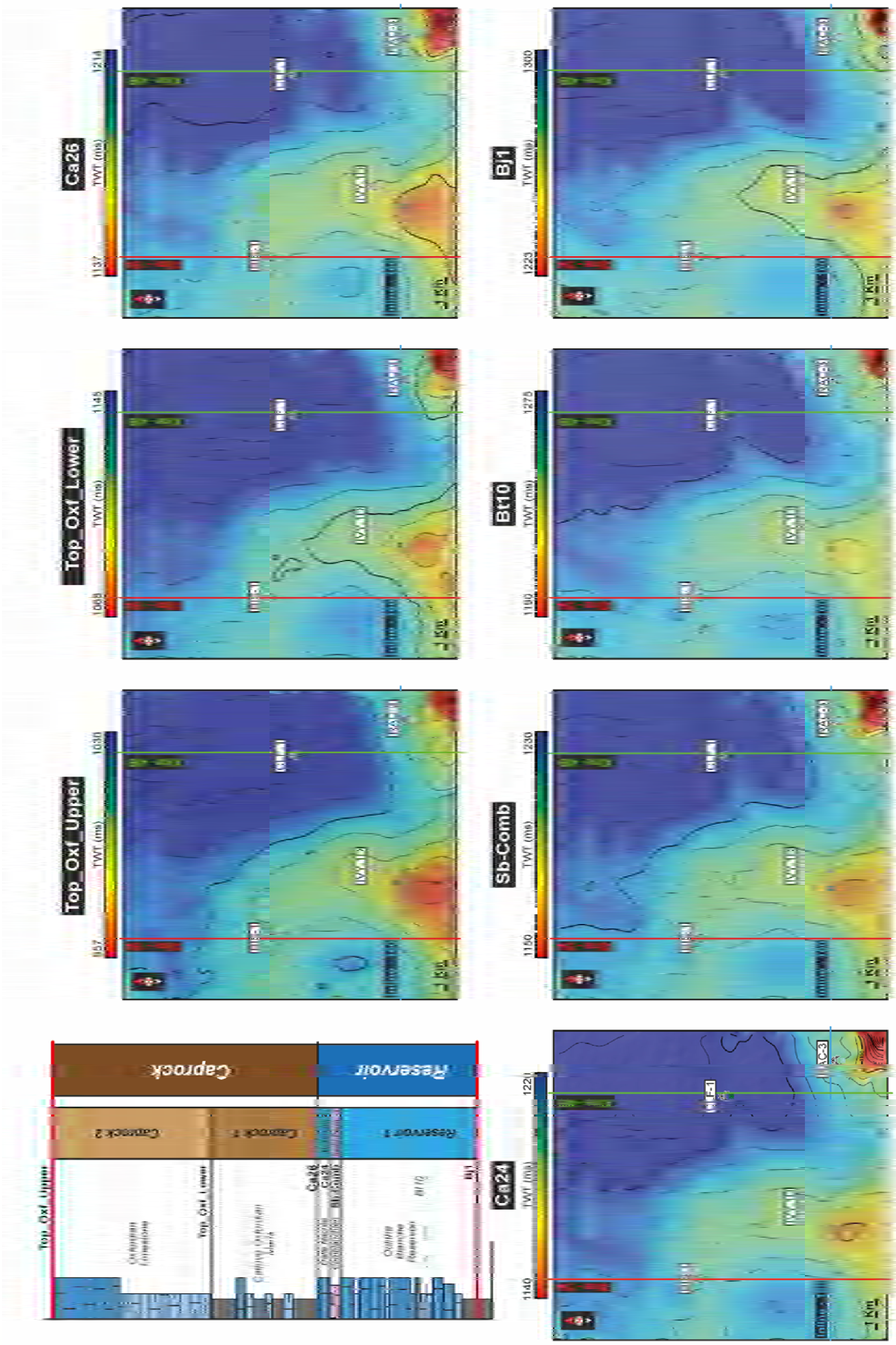

Figure 5-4: Isochron maps of storage complex horizons. Maps in Two Way Time (twt – ms).

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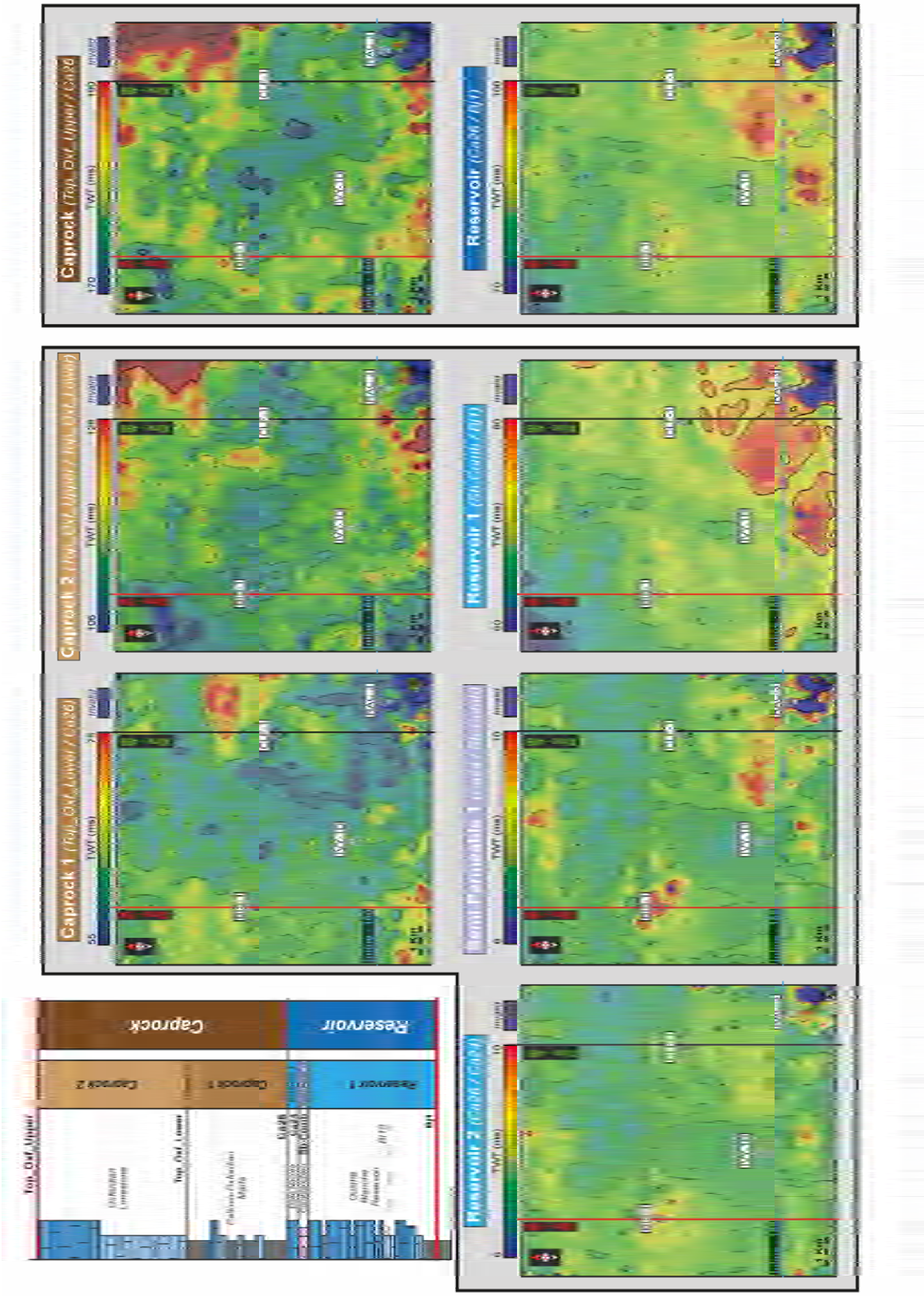

Figure 5-5: Isochore map of different reservoirs, semi-permeable and Caprock intervals of the Storage Complex. Maps in Two Way Time (ms).

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- **Unit II – Caprock 1 (Top_Oxf_Lower to Ca26)**

This second units is identified as the first caprock interval located above the reservoir section (Figure 4-7). Top of the unit is bounded by the horizons Top_Oxf_Lower, which correspond in the area as a major vertical facies variation from marls to tight limestone, respectively associated to Caprock 1 and Caprock 2 boundary. Bottom of the unit is linked to the Horizons Ca26, which highlight the transition from reservoir facies of the Dalle Nacrée Formation and the Caprock. Seismic unit is isopaceous with the absence of strong thickness variations (55 to 75 ms corresponding to 100 and 130 meters - Figure 5-4). Projected surface of the unit correspond to 110 Km^2. As observed along seismic lines, seismic unit do not present amplitudes variations with a tabular geometry and low amplitudes close to transparent horizons.

Combination of seismic units I and II correspond to the full caprock of the storage complex (Figure 5-5). The later represent a full isopaceous interval composed of marls and tight limestone (offshore mudstone). General thickness vary between 366 and 413meters, which is closely two time thicker than the reservoir itself.

- **Unit III – Reservoir 2 (Ca26 to Ca24)**

This unit represent the first reservoir interval defined in the storage complex. It is associated to the Dalle Nacrée Formation, which correspond to isolated oolitic shoal deposited during a transgressive stage. The Horizons Ca26 delimits top of the unit and its bottom correspond to the horizon Ca24. This seismic unit is isopaceous with a small thickness spanning between 6 to 10ms. This correspond to 12 and 20 meters. In terms of depth, the top of the reservoir is located between 1763 and 1682 meters below sea level. An attention have to be taken on uncertainties because of the actual seismic resolution which correspond to 4ms. Estimation of amplitude variations and internal geometry of the unit cannot be distinguish because of the low resolution and thickness of the Unit itself.

- **Unit IV – Semi-permeable 1 (Ca24 to Sb-Comb)**

Associated to the Calcaire du Comblanchien formation, this semi-permeable unit is important to characterise for static and dynamic modelling. Top and bottom of this seismic unit is respectively linked to horizons Ca24 and Sb-Comb. As previous seismic units, and shown on Figure 5-5, this unit do not present some thickness variations with a variation range between 6 and 10ms (11 and 25m). As describe before for reservoir 1 unit, these thickness variations have to be taken with precautions due to the seismic resolution, evaluated at 4ms. Consequently, due to the low thickness, it is not possible to specify internal geometry and amplitudes characteristics of the unit. However, analysis of the spectral decomposition of horizons in the seismic unit IV reveal a potential tidal channel features (Figure 5-6). In the north-western part, specific features with meander geometries, point bar accretion, meander neck and channel connexions. These features could be associated to tidal channels present in lagoonal deposit of the Comblanchien Formation and potentially associated to tidal-dominated depositional environment interpreted on cored sedimentary facies.

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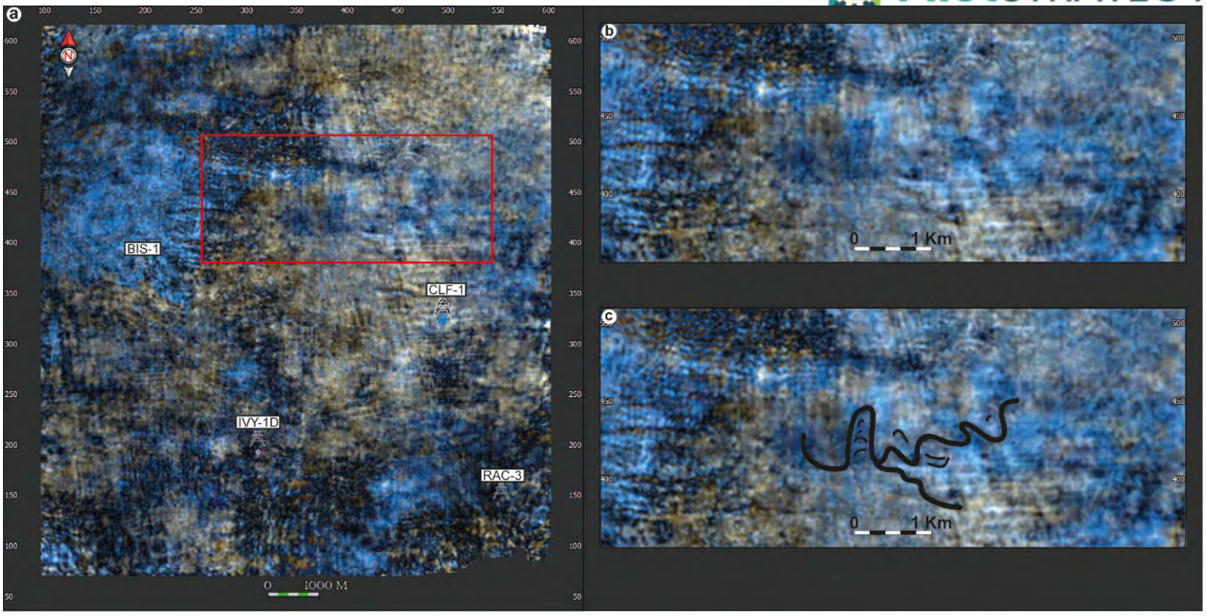

Figure 5-6: Colour blended (RGB) spectral decomposition attribute maps of the SB-Comb horizons where a potential tidal channel with its potential point bar accretion and meander neck could be interpreted.

Unit V – Reservoir 1 (Sb-Comb to Bj1)

This last unit correspond to the main reservoir interval targeted in this project. This unit correspond to the Oolithe Blanche Formation. In the detail, this reservoir section is divided into two interval with a first one denominated by a prograding system tract and bounded by Bj1 (bottom) and Bt10 (top) horizons. The second interval correspond to the aggrading system tract, bounded by the Horizon Bt10 and the Sb-Comb one. Actual delimitation of the reservoir complex do not integrate the Bt10 horizons, which will be use for internal architecture during static modelling. Processed thickness map indicate a potential thickening to the South East. This thickness variation is spanning from 80 to 60 ms, which correspond to 133 to 211 meters. Top and bottom of the seismic unit are conformable and do not highlight specific seismic reflexion termination (toplap or onlap). A slight fanning geometry could be interpreted in the seismic unit after an extreme vertical exaggeration. This trend is visible along the prograding and aggrading system tract. Then, step in the thickness map, observed on Figure 5-7 follow potential structural folds with a SW/NE direction. Seismic data do not show specific horizons offset in the reservoir complex or horizons above. Potential offset could be visible in Seismic units related to Trias interval. Regional tectonic quiescence during the onset of the Dogger platform, the absence of proper horizons offset related to structural accident and the slight fanning architecture of the reservoir would indicate a long wavelength differential subsidence to the southeast in the area during the Bathonian, potentially related to long wavelength deformation.

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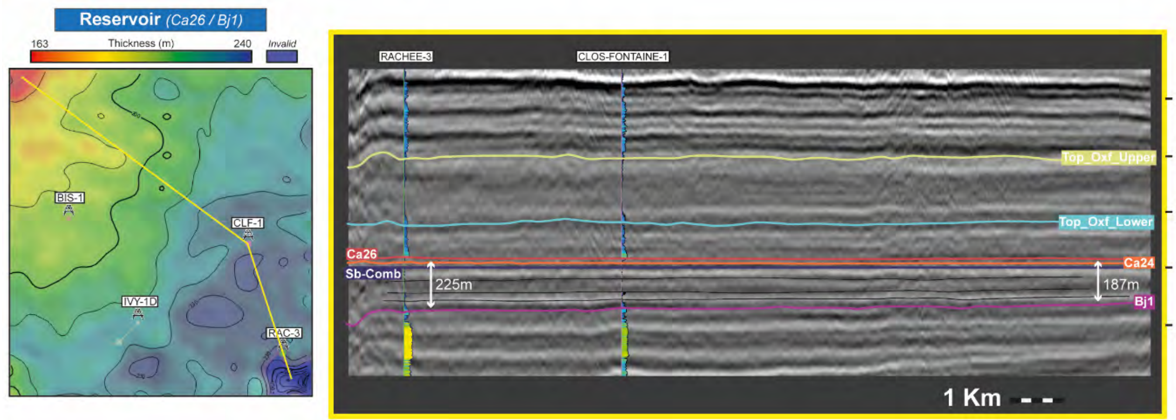

Figure 5-7: Thickness variation of the Reservoir interval along a NW-SE transect. Seismic line is flatten on the Sb_Comb Horizon.

5.1.2 Time-Depth conversion

In the prospected area, only the Clos Fontaine well has checkshots data and z velocity law. After the processing of the drift curve and the DT calibration, a Velocity and depth-time conversion model has been conducted along the CLF-1 well. For the three other wells, the lack of specific well data (Neutron Density) though the full sedimentary pile, do not let us to process a synthetic seismogram and consequently propose a velocity law for each well. CLF-1 well velocity law has been applied on others well and specific shifting has been proposed in objective to match well markers to specific horizons with high interpretation confidence. After a QA/QC, we can observe that maximum shifting is -2.1ms for at the well RAC-3. This shifting is acceptable, considering the 4ms seismic resolution.

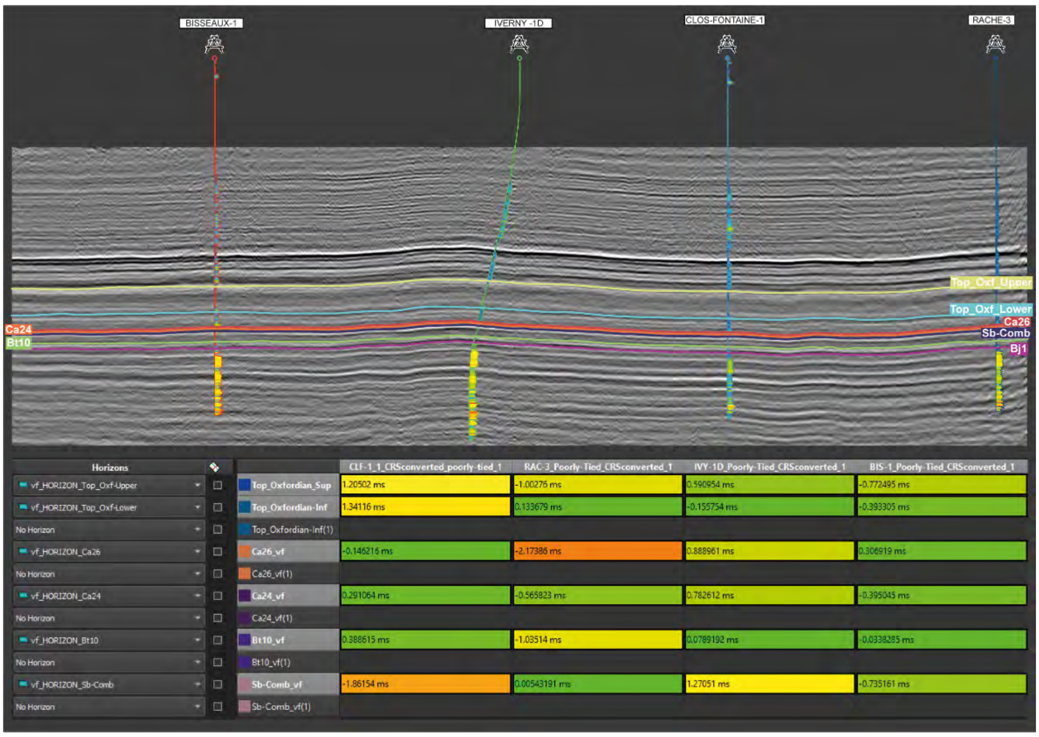

Figure 5-8: QC control between interpreted horizons and markers on the 4 wells present in the seismic area.

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Then, thanks to Paleoscan software, a 3D velocity model has been processed. This 3D velocity model is processed with i) velocity intervals from calibrated sonic of the 4 wells and ii) the relative geological time model (RGT Model), processed from the seismic interpretation of the full sedimentary pile (storage complex, over and underburden units). Interval velocity attributes has been propagated and interpolated along the general architecture of the RGT model. Due to the general tabular geometry of the sedimentary pile, we consider here that interpreted horizons represent the same time-line without any eroded interval.

As observed on Figure 5-9, the velocity model do not get the full sedimentary pile. It has been decided to start the velocitiy model at horizons Top_Albo-Aptian. This horizon is the first one with no artefact or noise from seismic processing and consequently a proper horizons in the RGT model. Then, by dichotomy, initial speed has been calibrated for each well. This initial speed correspond to 2320 $m.s^{-1}$ for CLF-1 well, 2380 $m.s^{-1}$ for RAC-3 $m.s^{-1}$ well, 2400 for IVY-1D $m.s^{-1}$ well and 2422 $m.s^{-1}$ for BIS-1 well. Thanks to the 3D velocity model and the initial speed, a time-depth conversion is proposed for each horizons interpreted. A quality control has been conducted and the maximum shifting observed correspond to 10 meters on converted horizons

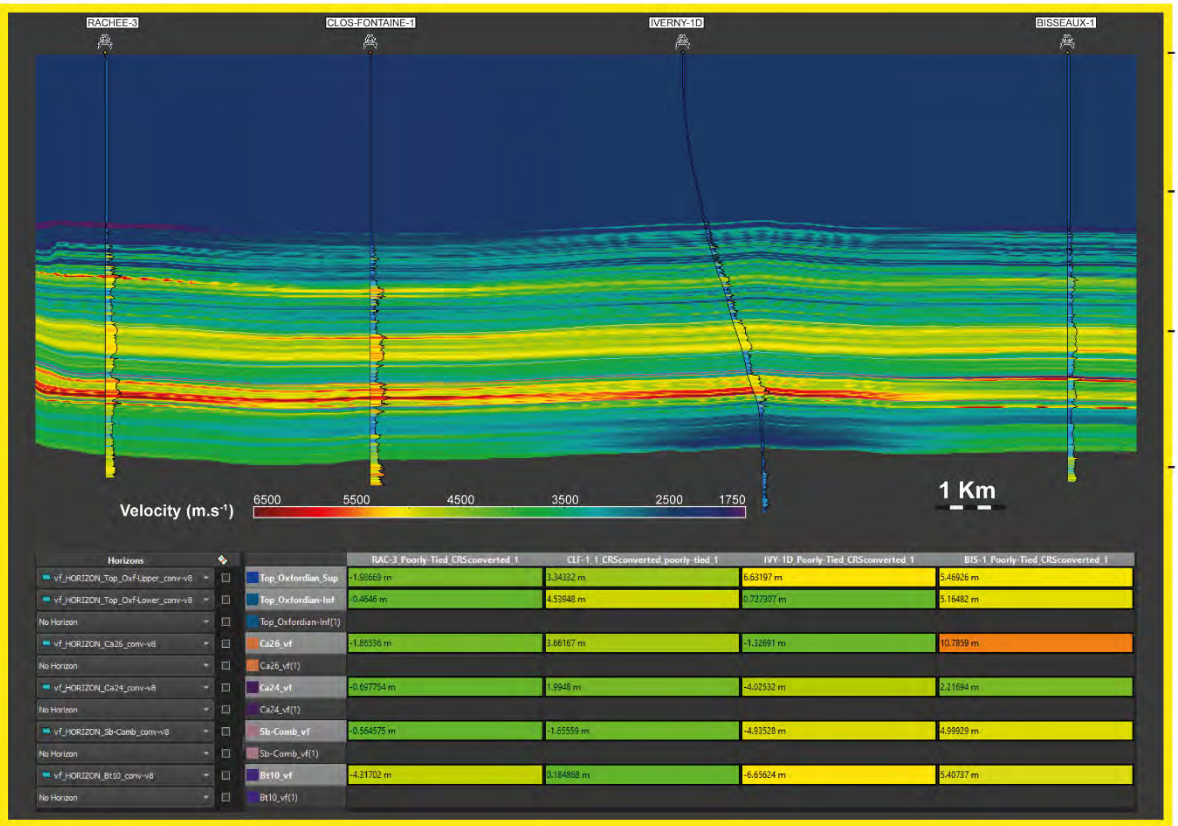

Figure 5-9: Processed velocity model along arbitrary line though the 4 wells in the seismic area and QC control on converted horizons.

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5.2 Trap(s) characterization

Seismic interpretation and isochron / isochore maps indicate potential structural trap in the restricted AOI. Due to the homogeneity and low lateral variability of the sedimentary units, stratigraphic trap are not considered in the study. Consequently, only structural traps are examined. Analyse of isochron maps off all horizons let the identification of two main structures defined as the Charmotte and Clos-Fontaines folds.

5.2.1 The Charmotte fold

The Charmotte fold is visible in the southern part of the area and affect all the sedimentary pile studied here. This structure dip to the north and bend to the west. As shown on Figure 5-10 and Figure 5-11, Charmotte anticline is 4 Km larger and get flatten to the north with 3.7Km large. 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 correspond to the structural trap from the southern Charmotte oil reservoir exploited by Vermilion Energy.

5.2.2 The Clos-Fontaine fold

The second structure, which we named Clos-Fontaine anticline, correspond to the small anticline visible on time maps from Top_Oxfordian-Low to Top_Rhetian. This small structure has a N45°E direction with a deepening to the East-North-East. This small structure affect only the base of the sedimentary pile, which comprise the studied reservoir complex. Its width is comprised between 1.8Km and 500m and its length is measured at 3 to 4 Kilometres. On seismic data, a fault is observed at the edge of this structure, which mostly impact triassic sedimentary units.

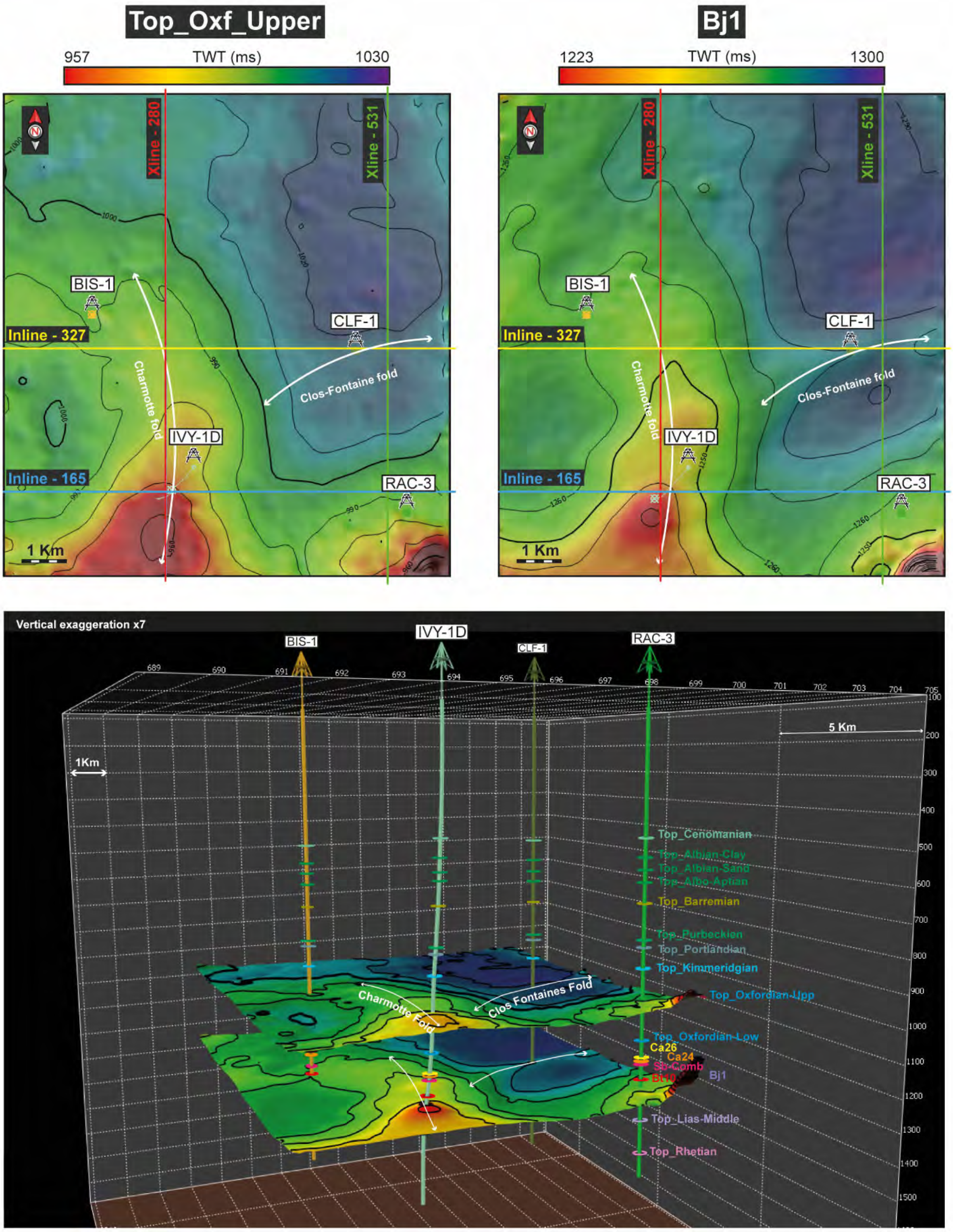

Figure 5-10: Map and 3D view of the Charmotte and Clos Fontaine folds

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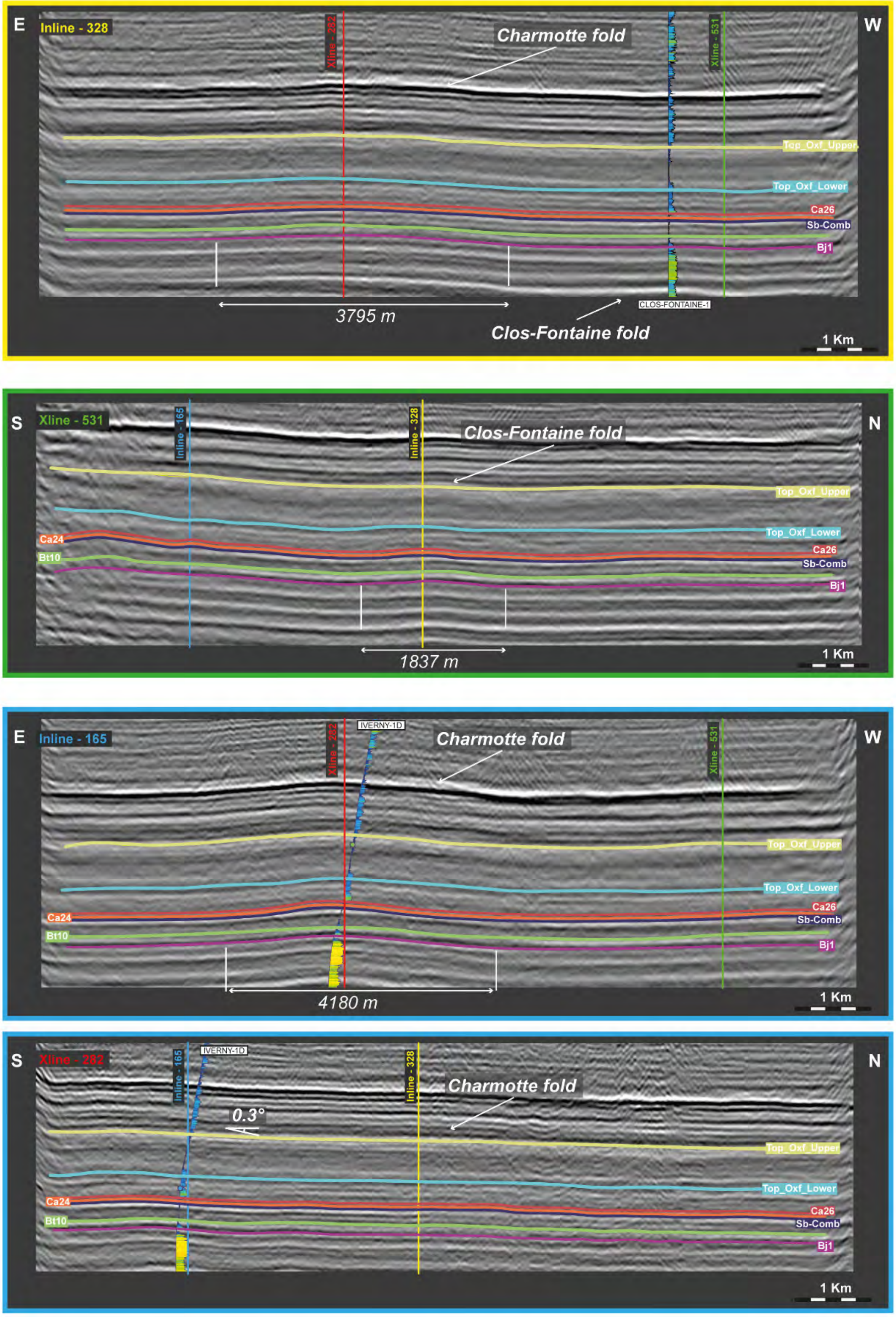

Figure 5-11: Interpreted seismic line showing Charmotte and Clos Fontaine folds. Seismic line location are shown on Figure 5-10

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5.3 Log analysis and Petrophysics

5.3.1 Qualitative study – depositional environment determination

A qualitative study has been conducted on all well logs used in the study, from extended to the restricted area. This interpretation consisted to interpret specific depositional environment interpreted along sedimentary cores and general knowledge of the Dogger carbonate platform. Seven depositional environment has been interpreted along the 47 wells. These domains corresponds to: Upper offshore, Lower offshore, tight, outer shoal, shoal, lagoon, and condensed. This domains are slightly different compare to depositional environment interpreted. Outer ramp domain has been divided into two domain. First one correspond to a deeper part, probably composed of packstone / wackstone, associated to tight limestone. Second one is closer to shoal domain which propose more grainy facies with potential better reservoir characteristics (porosity / permeability). Then, tide-dominated and lagoon depositional environment are regrouped into an unique domain resumed as lagoon. Finally, condensed domain is specifically dedicated to specific reservoir interval where potential Hard Ground could develop. This is more associated to facies than depositional environment interpretation.

Depositional environment from sedimentological description	Depositional environment interpreted on well logs
Upper offshore	**Offshore sup**
Lower offshore	**Offshore inf**
Outer ramp	**Tight limestone**
	Outer shoal
Shoal / Middle ramp	**Shoal**
Back-shoal	
Tide-dominated lagoon	**Lagoon**
Lagoon	
Condensed	

Figure 5-12: Table resuming relationship between depositional environments interpreted though sedimentological facies from core and well logs data.

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After interpretation, 47 wells of the extended AOI has been interpreted. Figure 5-13 shown an example of this interpretation along the CLF-1 well. Relationship between depositional environment interpretation, sequence stratigraphic scheme and vertical facies variation are clearly linked. Along the full study, shoal domain represent the biggest part of the reservoir complex with an average of 40% abundance. Then, offshore (upper / lower) and outer ramp domains re interpreted. Lagoon is only present at 8%, which follow the poorly developed Lagoonal facies, visible along the Comblanchien Formation.

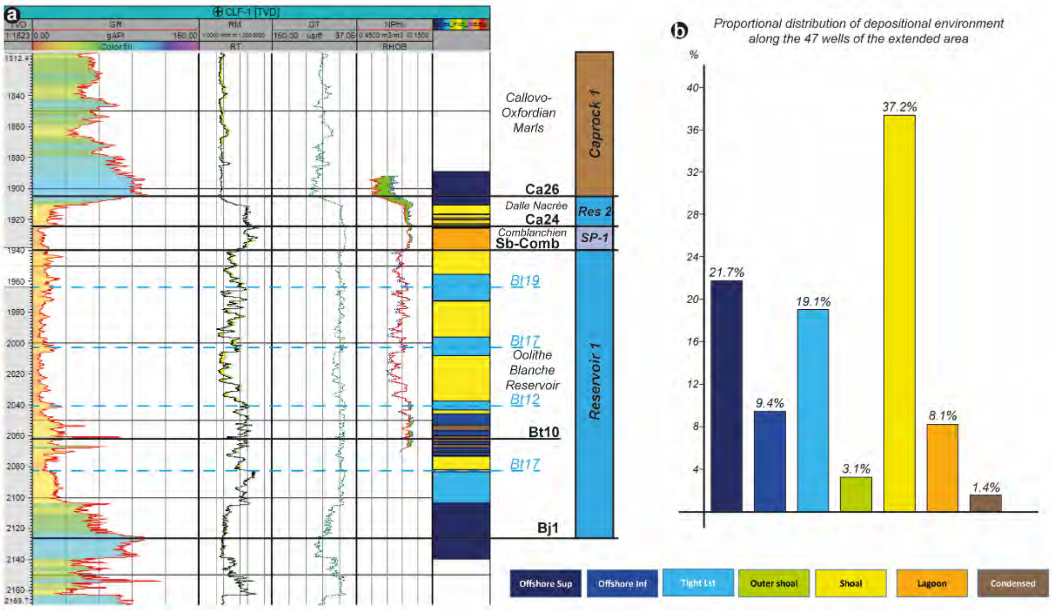

Figure 5-13: a. Example of qualitative depositional environment interpretation along CLF-1 well. b. Histogram showing the proportional distribution of depositional environment along the 47 wells of the extended AOI.

5.3.2 Quantitative analysis – Rock-type classification

Thanks to the high number of well logs on the 47 borehole present in the extended area, a rock-tpe analyse has been possible. Electrofacies study propose here has been done on two different way. Thanks to the presence of core and sedimentary facies classification, a supervised and unsupervised rock-type (RT) classification has been conducted. As well RT classification has been driven in objective to distinguish and classify the best reservoir facies and not specific sedimentary facies. As observed on the sedimentary analysis, reservoir properties in the dogger ramp is mostly driven by ooids vs bioclast distribution and diageneses. Consequently, RT study only focus on the classification from poor to the best reservoir qualities.

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5.3.2.1 Unsupervised study: Preliminary electrofacies cross plotting

Because specific logs has not been processed on all well logs of the restricted area, only basic petrophysic log has been used for the unsupervised RT study. Four specific cross plot has been used: SONIC on Neutron Porosity ; Acoustic Impedance on Neutron Porosity ; Gamma Ray on Neutron Porosity ; and Density on Neutron Porosity. Neutron Porosity has been every time used in cross plot because it indicate the potential porosity of the system and already calibrated for limestone. As well, it has been decided to add a third plot by point colouring linked to the Gamma Ray value. This colour indication let us to identify porous and argillaceous facies, which are directly interpreted as offshore facies.

Analysis of different cross plotting let us to distinguish five to six group of points that we denominate EF1 to EF5 (or EF6) from the lowest to highest porous RT. Noteworthy, first electrofacies is everytime linked to high porosity and high gamma ray value, which let us to consider it as marls facies. Figure 5-14 indicate the different classification. After plotting them on logs and comparing with Effective porosity and reservoir flag, it appears that most of the different cross plotting are similar and fit with effective porosity trends. This is explain because of the common use of the Neutron Porosity as abscise for each cross plot. However, some limits could already be considered for acoustic impedance and Gamma ray cross plot which do not fit perfectly with effective porosity logs.

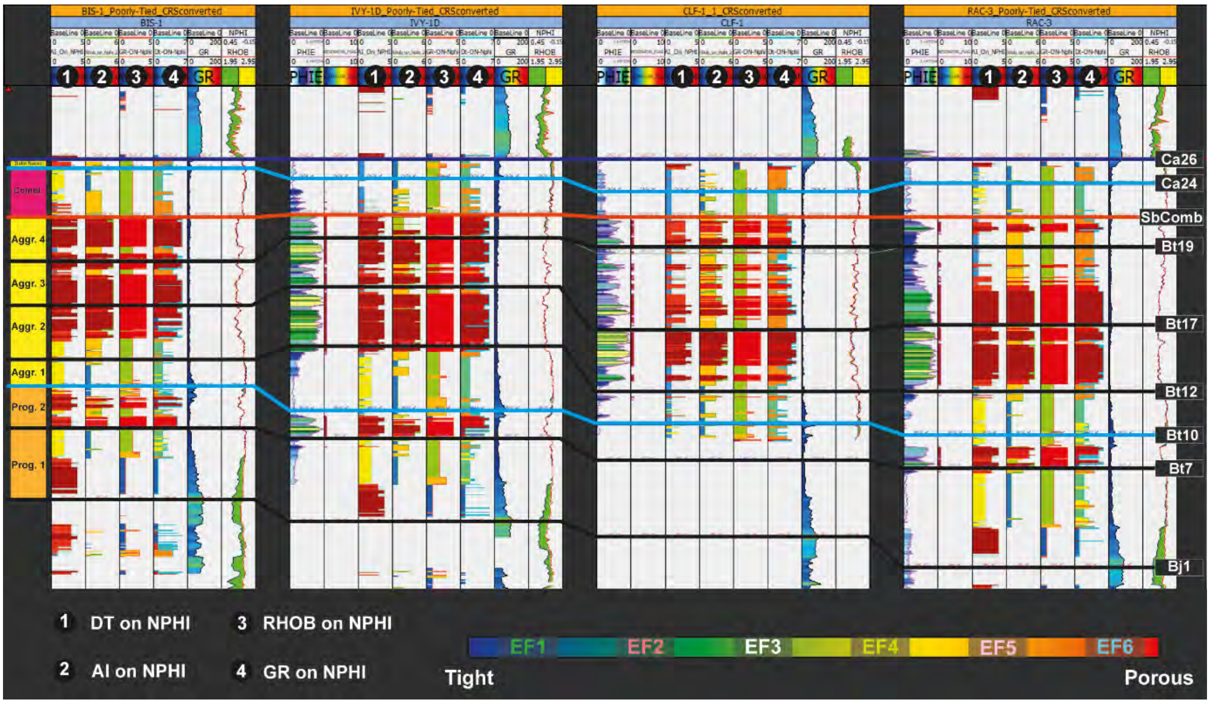

Figure 5-14: vertical plot of different rock-type classification done on the 4 comparison presented in the text above.

In objective to have a better classification, it has been proposed to realise the same study, only on log intervals where sedimentary description has been conducted.

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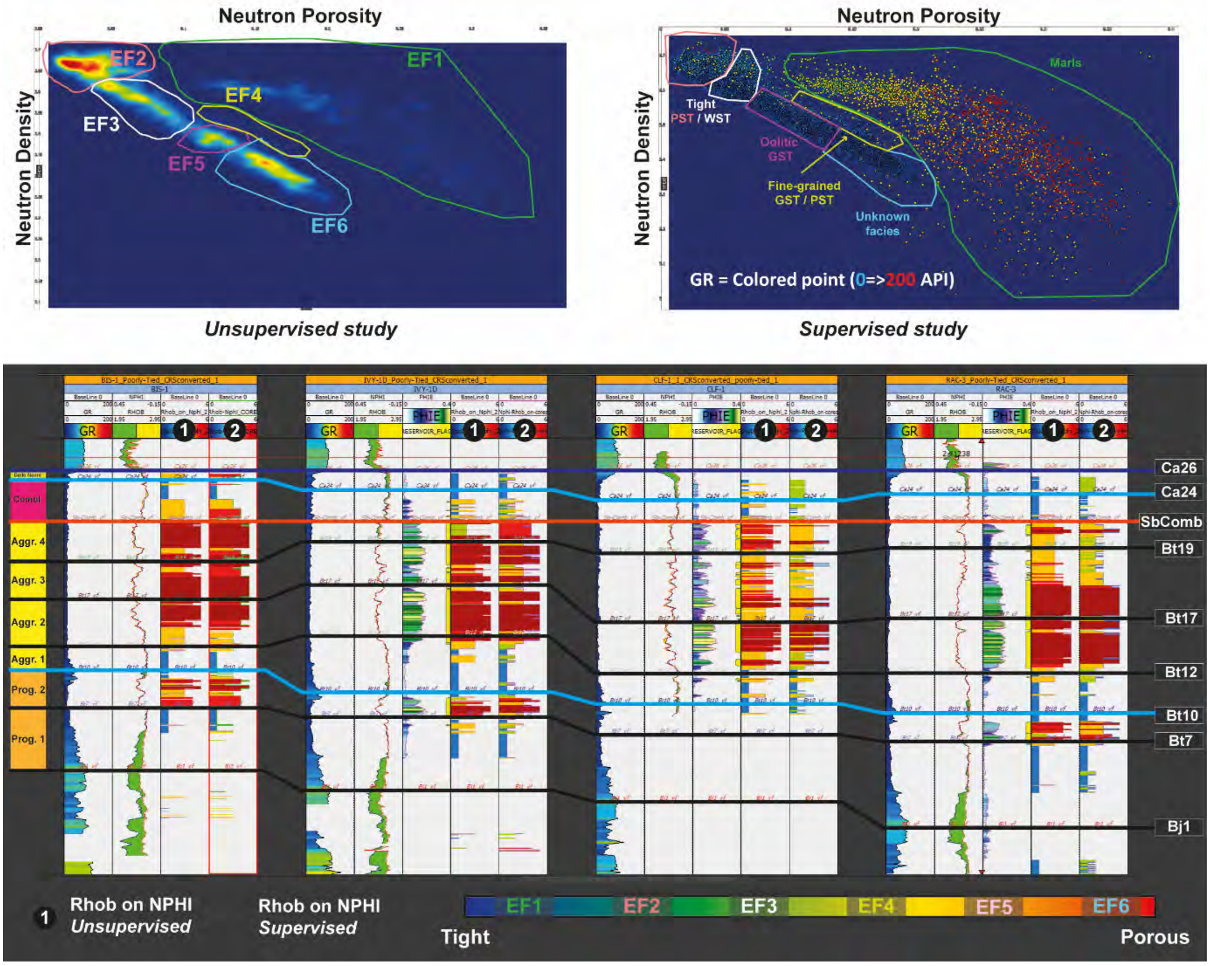
5.3.2.2 *Supervised study: core calibrated electrofacies*

A similar cross plotting work has been conducted on logs where sedimentary facies description has been done on core. This approach reveals that Density on Neutron Porosity cross plot and RT group fit with reservoir facies identified. Electrofacies comparison indicate that from EF1 to EF5, each electro facies correspond to Marls, bioclastic packstone, oolitic or bioclastic wackstone / grainstone, oo-bioclastic grainstone, and very-fine grainstone. Last electrofacies (EF6) is not identified on core because of its distribution in the deeper part of the reservoir. Unfortunately, this facies looks like the one with the best reservoir properties. This is probably linked to similar facies with less cementation due to diageneses.



Consequently, cross plotting between density and Neutron Porosity appear to be the best correlation for rock-type classification and conduct us to indicate along all the wells, the potential distribution of the best reservoir facies.

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5.4 Well-Seismic stratigraphic correlation

All horizons interpreted on the seismic data corresponds to specific markers identified on wells. They corresponds to specific shifting of well logs like Gamma ray, resistivity and Neutron Density; which indicate a variation of sedimentary facies, or lithostratigraphic units. This interpretation, followed by correlation between wells has been done on the 47 wells presented in the extended area.

This identification and well log correlation has been interpreted thought the full sedimentary pile and specific markers of the storage complex. Table presented in annexe 5 describe all markers, their corresponding horizons and link to the storage complex of the studied area.

12 correlations has been interpreted along the extended area. Two preferential direction has been used with a NE-SW and NW-SE. Respectively, these directions corresponds to dip and strike direction of the carbonate ramp general progradation. Figure 5-15 show two well logs transect which give an overview of the reservoir architecture. This correlation and interpolated surfaces of the full markers will be used for model architecture in the extended AOI.

Figure 5-15: Example of well-log correlation done in the extended area of interest following the dip and strike direction of the oolitic ramp system.

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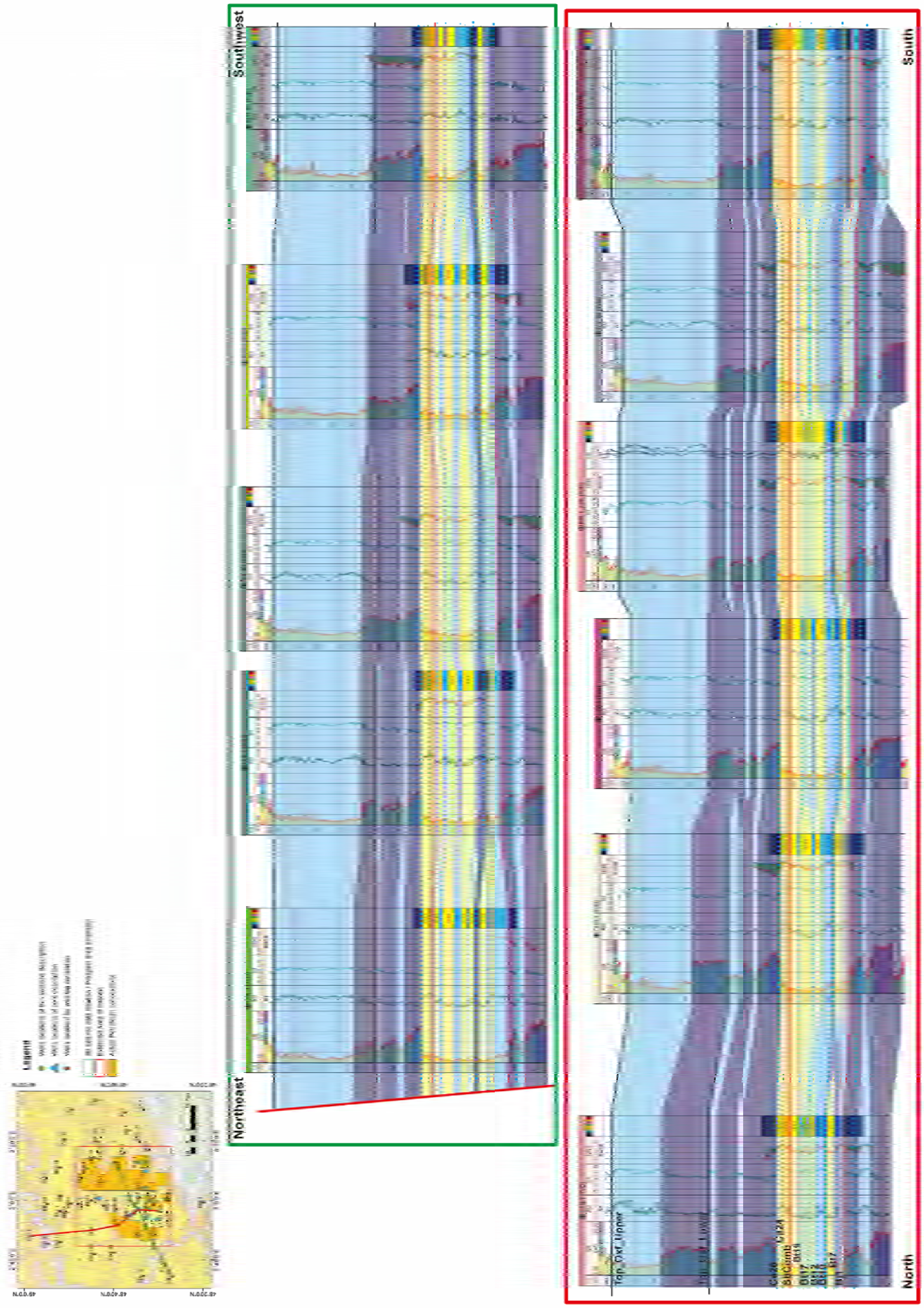

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5.5 Reservoir Facies properties

Thanks to the high number of plug data, compared to the literature and reservoir properties of similar facies into geothermal well in the Paris Basin, we can easily provide two different kind of reservoir properties for the different facies identified in the reservoir. First properties delivered correspond to an average and Porosity-Permeability (K/Phi) relationship lax for each depositional environment identified along well data. Second properties proposed here correspond to porosity and permeability average and K/Phi law for each rock-type identified in the reservoir.

5.5.1 Reservoir Properties by depositional environments

Along the 372 meters cores described and sampled for reservoir properties characterisation, only four depositional environment has been defined through well log data. These depositional environment corresponds to lower and upper offshore, shoal and Lagoonal environments. Lower offshore cannot been sampled and plugged for reservoir properties characterisation because of marls rheology. Consequently, only Lagoon, shoal and upper offshore has been sampled. As well, outer ramp system (tigh and outer shoal environment) and condensed interval has not been described and sampled.

5.5.1.1 Upper offshore depositonal environment

Only three samples characterised this environment. Consequently, it's not possible to propose a relation law between porosity and permeability measures. We will here proposed one single measures, which is representative to the specificity of this marl facies with a good porosity but a very low permeability measure. The table below present the reservoir properties for samples of the upper offshore depositional environment. For reservoir properties, we propose to get a porosity at 5% and a permeability average arund 1.5 (µD).

	Name	Well	Depth (m)	Porosity (%)	Kw (µD)	PE (bar)
4856	CHM4_C1_1800,5	Charmottes 4	1800.5	8%	0.4	~ 0,5
4857	CHM4_C1_1803,25	Charmottes 4	1803.25	4%	0.8	~ 1
4866	VUS1_c6_1843,45	Vulaines 1	1843.45	4%	0.007	42 - 46
4867	VUS1_c6_1844,05	Vulaines 1	1844.05	5%	5	1.0 – 1.5

5.5.1.2 Shoal depositional environment

Shoal environment has been sampled 104 times. Porosity measures indicate a mean around 10% with a standard deviation of 5.3%. Permeability measured indicate a 51.3 md mean with a standard deviation calculated at 80.55 mD. Maximum measured value correspond to 1.8 darcy. Plotted on permeability-porosity relationship graph, we can observe that measures doesn't follow the correlations btained in Catinat et al., 2023, associated to similar depositional environment in the central paris basin and as well, do not follow analyse proposed in the deliverable 2.3. This is mostly explained of the interval sampled with is more impacted to diageneses which plugged the porosity.

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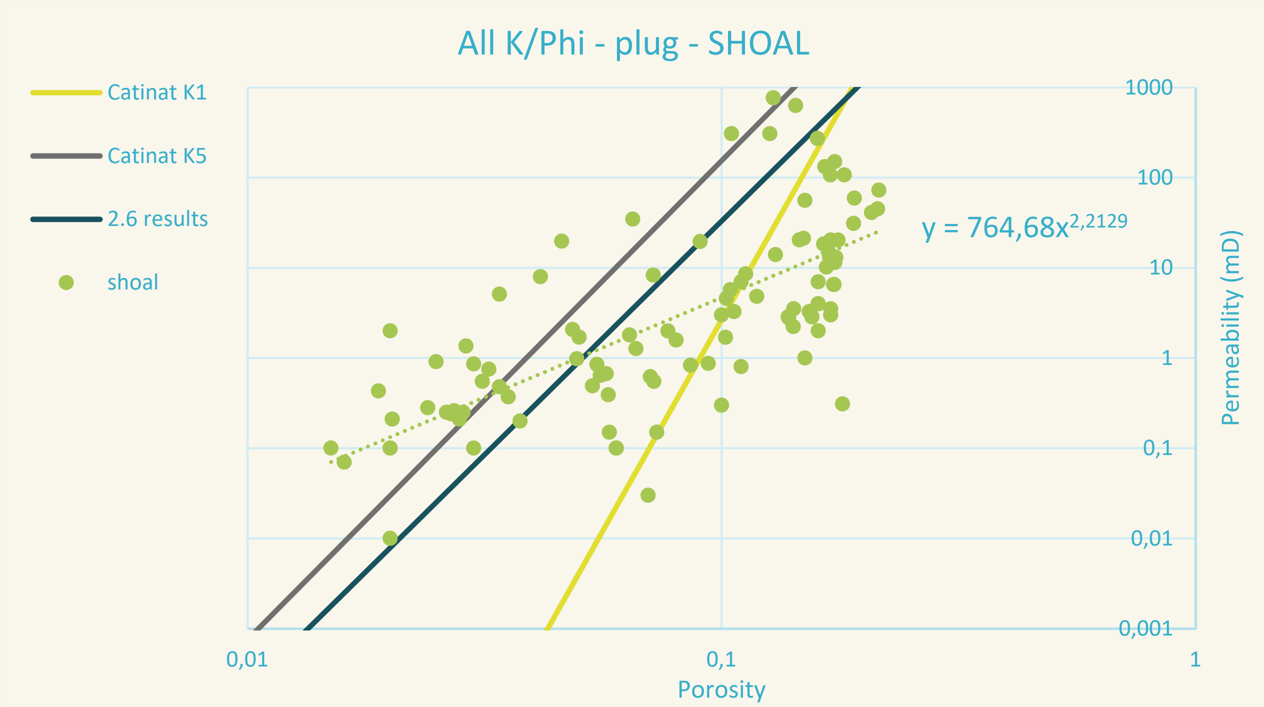
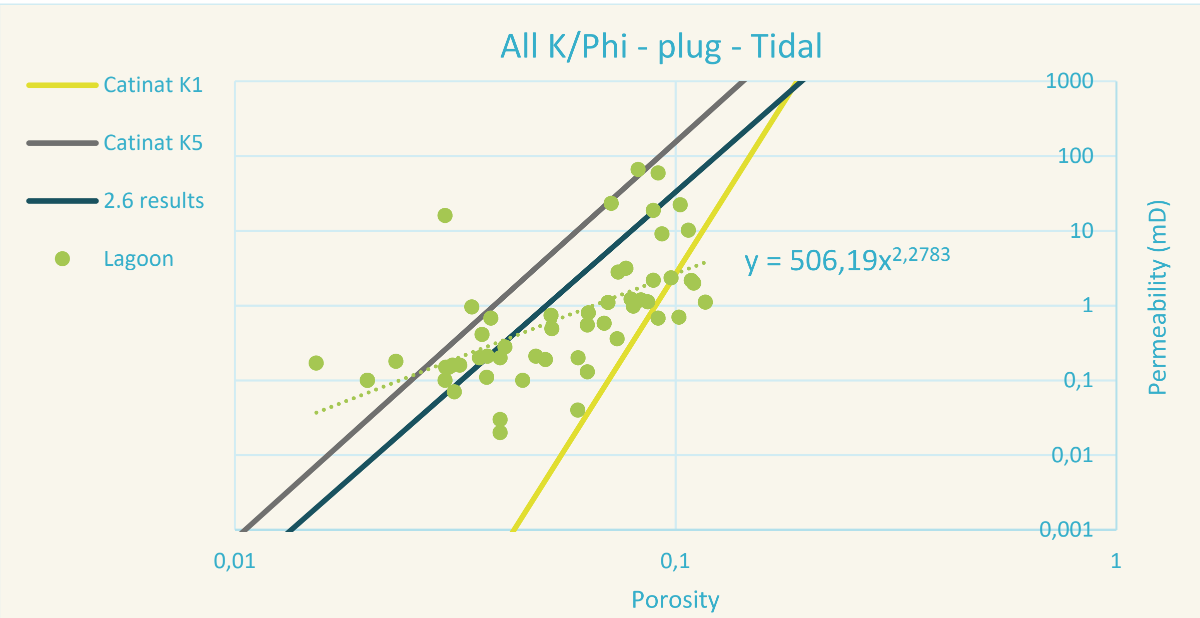


5.5.1.3 *Lagoon depositional environment*

Lagoon environment has been sampled 55 times. Porosity measures indicate a mean around 6% with a standard deviation of 2.8%. Permeability measured indicate a very low permeability with 4.7mD has a mean with a standard deviation calculated at 6.8 mD. Maximum measured value correspond to 66 mD. Plotted on permeability-porosity relationship graph, we can observe that measures has the same trend as the plot of shoal depositional environments.



Corss-plot comparison and K/Phi relationship law obtained and compare with data from the literature indicate that results obtained in this study are not well comparable. After the comparison with rock-

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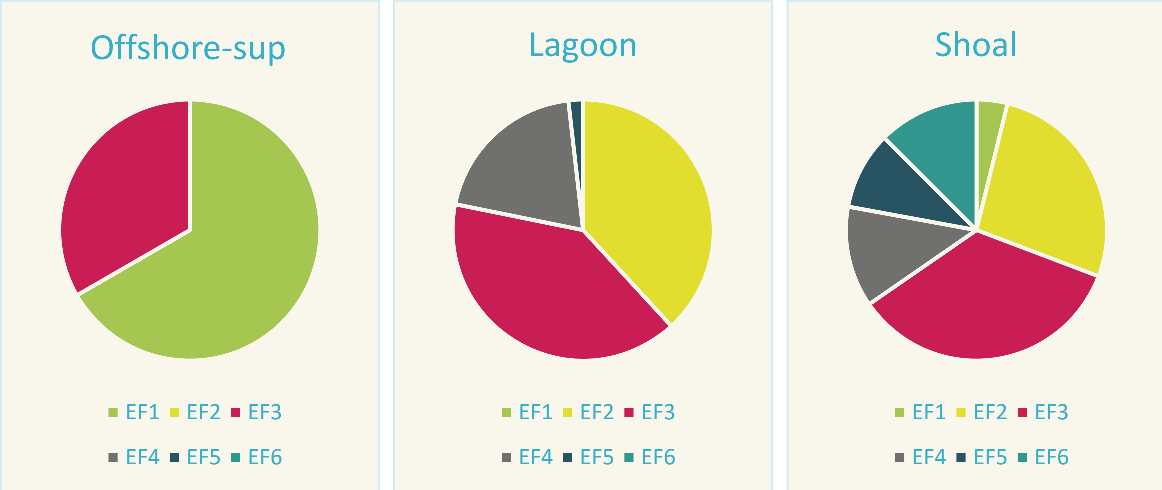
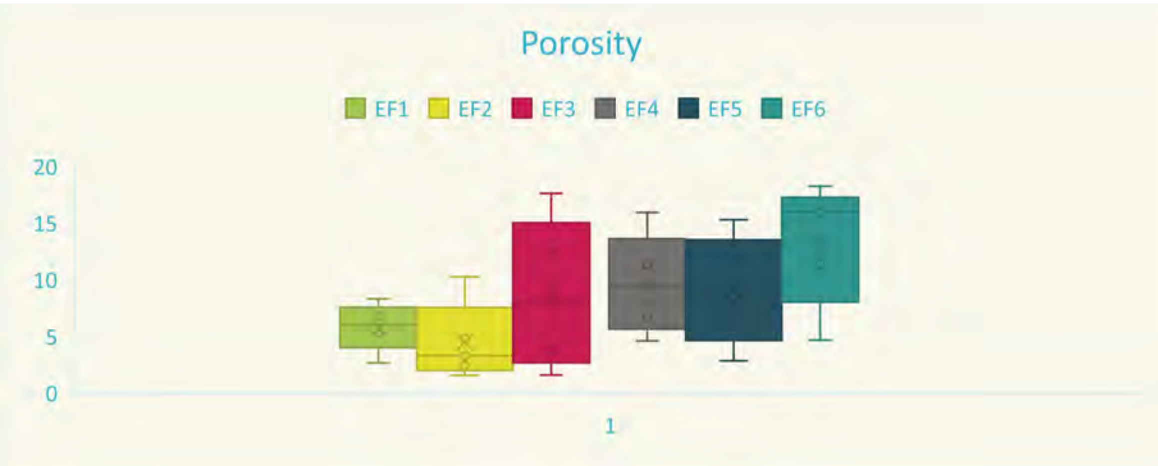
type study, we can see that each interpreted depositional environment are composed of many different rock type (see graph below). Consequently, porosity-permeability relationship could be observed through the rock-typing classification than depositional environments.



5.5.2 Reservoir properties by calibrated rock-type.

As presented in the section 7.3.2.2, Six different rock-tupe has been identified along well data from the studied area. Compared to core data, these electro facies let us to link directly sedimentological facies, depositional environment and Rock-type. Compared to the 371 measures available for this study we can provide for each rock-type a porosity, permeability and K/Phi relationship law for each rock-type.



5.5.2.1 Rock-type EF1 and EF2

Respectively identified 24 and 162 times, Rock type EF1 and EF2 correspond to marly / argillaceous limestone facies, generally associated to offshore and lower shoreface environement. These rock-type could be as well automatically detected in shoal and lagoon environement. They generally signed non-porous facies. Median porosity correspond to 5.9 % for EF1 and 4.2 for EF2. The median permeability measured correspond to 1.2 mD for EF1 and 15.4 mD for EF2. A porosity-permeability relationship is proposed for each rock-type.

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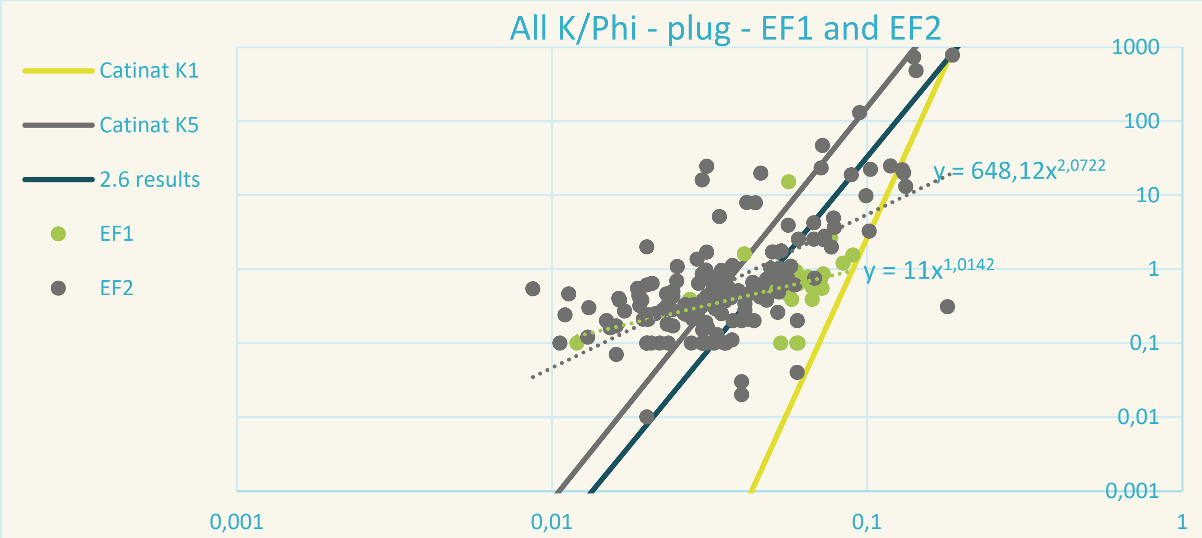

In the graphic below, we can see that K/Phi relationship do not follow trend observed by Catinat et al. (2023), obtained onto total and macro-porosity for dogger reservoir facies. As well, these plot do not follow the rend obtained in the petrophysici study presented in the deliverable 2.3. In conlusion, we can propose for this two rock type, to only keep median measured obtained on porosity and permeability.

5.5.2.2 Rock-type EF3

Rock type EF3 is characterised for 122 plug measures. This rock-is associated to first un-cemented facies presenting some porosity, which would drive the reservoir of the storage complex. Median porosity correspond 4.2 % with a standard deviation measured at 4.4. The average porosity measured correspond 15 mD with a standard deviation measured at 66 mD. A porosity-permeability relationship is proposed the relation-ship equation correspond to:

$$k = 1125.3 \times \theta^{2.2861}$$

This relationship equation still doesn't fit with equations proposed by Catinat et al., 2023 or equation proposed in the deliverable 2.3. Indeed, these facies were not the target for sampling stratefy, mainly focused on EF5 rock-type. However, we could proposed this relationship in the objective to have an accurate reservoir model.

5.5.2.3 Rock-type EF3

Rock type EF4 is identified 28 times along the different plug measured. This rock-is associated to slightly tight facies compare to EF5 and EF6. Typically, these rock-type represent very fine grained grainstone observed along Iverny-1D core. It offers a good porosity an average at 9.6% and a measured standard deviation. The average permeability measured correspond 24 mD with a 34mD as a measued standard deviation. The equation below represent porosity-permeability relationship obtained for the rock-type EF4:

$$k = 4524.1 \times \theta^{3.0227}$$

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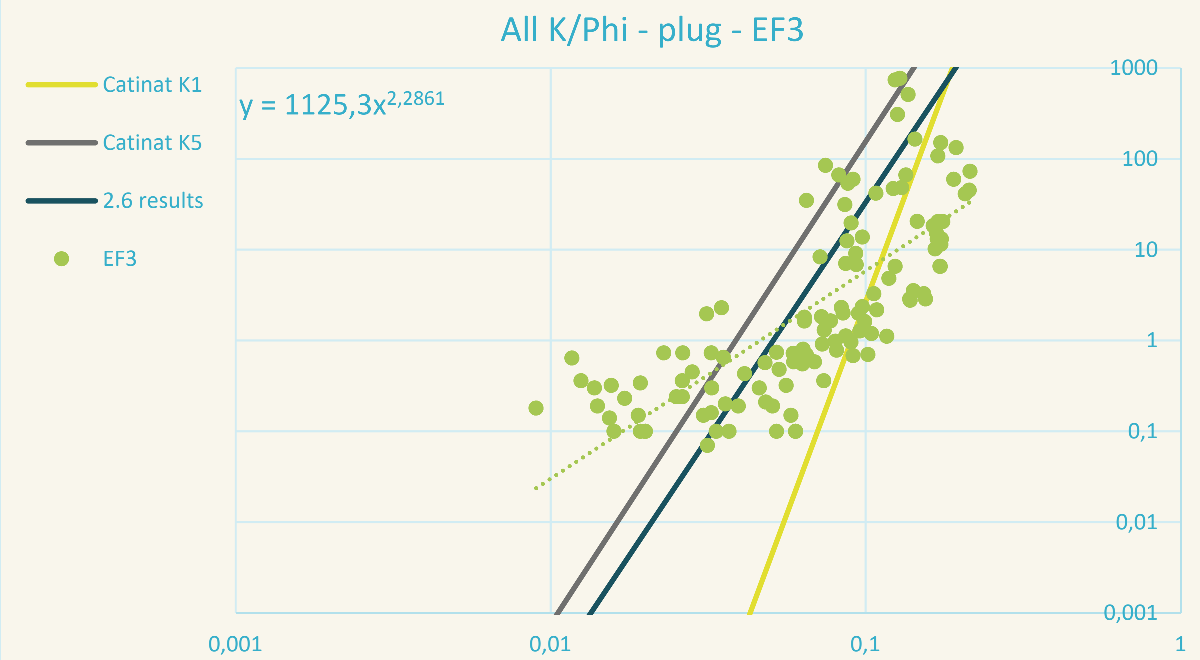

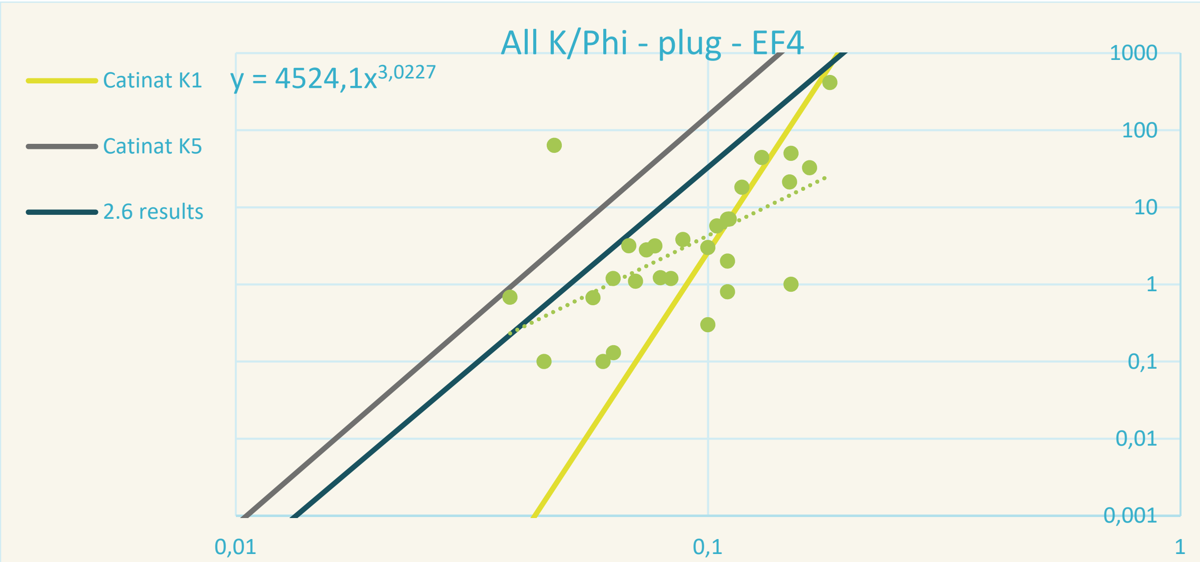

5.5.2.4 Rock-type EF5 and EF6

Rock type EF5 and EF6 represent the best quality in term of reservoir properties. They are generally associated to oolitic / oo-bioclastic grainstone presenting a good macroporosity, with the presence of dissolution figures. These rock types are represented by 15 measures for EF5 and 19 measures for EF6. Respectively, the average measured porosity value correspond to 9.2% and 13% with a standard deviation at 3.4 and 3.7. The average permeability measured correspond respectively to 256 and 40 mD. Equations presented below represent porosity-permeability relationship obtained for rock type EF5 and EF6:

$$EF5: \quad k = 545565 \times \theta^{4.4662}$$

$$EF6: \quad k = 1628.7 \times \theta^{2.3747}$$

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We can see that the equation, showing the porosity-permeability relationship for rock-type EF 5 follow the equation proposed in the deliverable 2.3. This is mostly due to the sampling strategy, dedicated to the most reservoir facies identified on cores. Unfortunately, EF6 corresponding facies was not present when sampling was processed.

Compared to Catinat et al. (2023) study, the Rock-type EF5 can be associated to macro-porosity. I conlusion, we propose to use porosity-permeability relationship for EF4 to EF6 and keep an average value for non-reservoir rock-type associated to EF1 and EF2.

5.6 Seal Facies properties:

General architecture, framework and distribution of the seal is already presented in sections before. It corresponds to the succession of the respective lithostratigraphic units, the Callovian Marls and the Oxfordian limestone. As presented before, this two units are generally isopaceous and their thickness expend respectively between 100 to 130 meter and 246 to 297 meters.

Unfortunately, an important lack of information is present for the seal facies. First, cores use for this study are form oil and gas exploration which every time target the reservoir itself. Consequently, oit was impossible to have an access to core which sample the Caprock. As well, it is not possible to sample some outcrops where the same lithostratigra^hic unit (Callovian marls). Consequently, we cannot propose an accurate value for seal properties. Only the measures realised onto the transition between the reservoir and the seal is proposed in the deliverable 2.3.

The pore size distributions measured by mercury injection indicate that the samples are essentially composed of microporosity (pore entry size < 2 µm); they have a low porosity and a low permeability, and sometimes very low (7 nD). The measured entry pressure values are relatively mall (1 bar) when the permeability is of the order of 1 µD and much larger (44 bars) when the permeability is very small (10 nD).

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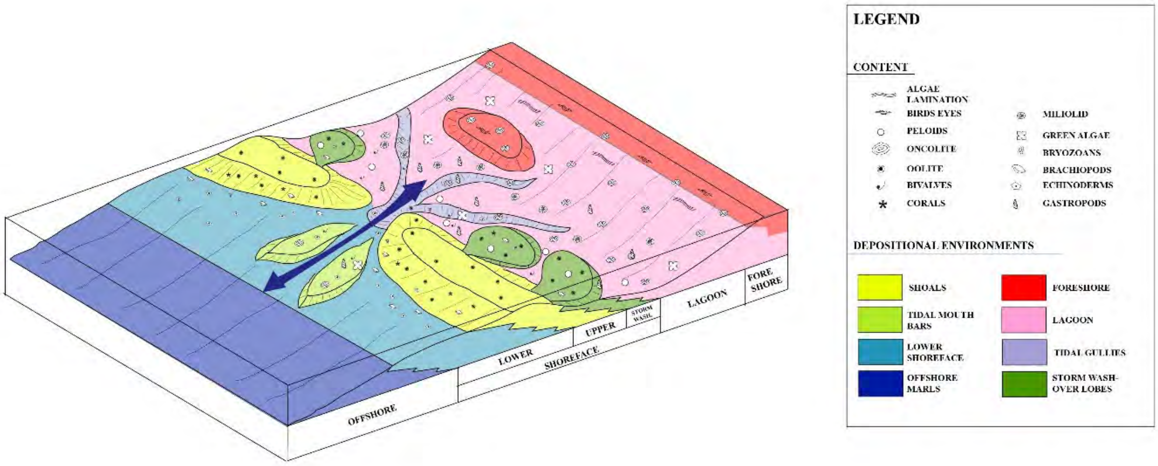
6. Depositional environments and geological conceptual model



This depositional profile depicts a typical carbonate ramp profile with development of shallow oolites-type barrier in the mid-ramp position. This latter separates an open-marine domain dominated by fair-weather and storm waves (respectively lower shoreface and offshore) from a restricted domain (lagoon). The distal depositional profile (blueish color) spans texture ranging from marly mudstone to wackstone attesting for depositional process dominated by decantation (offshore marls) and storm (mudstone-wackstone with bioclast alignment). Fauna association is typical of open-marine conditions with corals, bryozoans, brachiopods and crinoïds. The mid-ramp shoreface environment (yellowish color) corresponds to oolites and bioclast shoals organized in grainstone-packstone. They display megaripples and fauna association with: brachiopods, corals, bryozoans, crinoïds. When storm currents are strong-enough, part of these shoals is reworked land-ward as storm wash-over deposits (greenish color). It consists of fan-like geometries with open-marine dominated fauna and in minor proportion of more restricted-type fauna/biogenic elements (pellets, green algae and oncolites) and grainy-texture (grainstone to packstone). The inner-ramp corresponds to lagoon-type deposits (pinkish color) characterized by muddy textures (wackstone-mudstone) rich in green algae, miliolids, gastropods and oncolites. Very locally, oncolites-riched grainstone to rudstone attests for shoal to foreshore depositional environments (reddish color). Some grainy facies (grainstone to paskctone) displaying both inner-ramp and outer-marine fauna (miliols, oncolites vs. crinoïds and bryozoans) are more likely to be tide-dominated facies interpreted as mouth-bars in shoreface position and gullies in the lagoon. References

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8. Annexe

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8.1 Annexe1 -Well-log data

WELL-ID	WELL-TYPE	WELL-NAME	WELL-ID	DRILOPER	SPDDATE	ENDDATE	TD	STRATI-TARGET	GR-ALT	RT-ALT	XI2E	YI2E	BRGM-IND	WELL-LOGS	CORES	THIN-SECTIONS
14-4073-	Exploration	BOIS BRULE	BBL-1	SNEA(P)	19-févr-87	21-mars-87	2553	SOCLE	73,28	80,18	617699	2395162	02581X0098	In Database	NO DATA	NO DATA
14-1122-	Exploration	BOUCHY LE REPOS	BC-1	RAP	20-mars-56	23-août-56	2754,1	KEUPER SUP.	189,4	193	685454	2403401	02227X0002	In Database	NO DATA	NO DATA
14-3850-	Exploration	BISSEAUX	BIS-1	ESSOREP	30-janv-86	17-févr-86	2623	KEUPER INFERIEUR	109,2	113,9	642836	2401272	02215X0039	In Database	DESCRIBED	NO DATA
14-3737-	Exploration	BREMONDERIE	BRM-1	ESSOREP	09-oct-84	16-nov-84	2801	KEUPER INFERIEUR	123	130	649552	2386678	02596X0039	In Database	NOT DESCRIBED	DESCRIBED
14-3878-	Exploration	BRUYERES	BRU-1	ESSOREP	16-sept-85	09-oct-85	2593	SOCLE METAMORPHIQUE	130	138	643910	2427440	01855X0057	In Database	NO DATA	NO DATA
14-4021-	Exploration	BERTHUIS	BTS-1	ESSOREP	12-mai-86	02-juin-86	3000	KEUPER INFERIEUR	115,41	122	644225	2429994	01855X0058	In Database	NO DATA	NO DATA
14-4032-	Exploration	CHAUCONIN	CAN-1	SNEA(P)	05-oct-86	28-oct-86	2474	SOCLE METAMORPHIQUE	95,3	102,2	633958	2441758	01548X0042	In Database	NO DATA	NO DATA
14-3666A	Extension	CERNEUX	CER-1D	TOTAL EXPLO	20-nov-88	11-déc-88	2149	BATHONIEN	169,1	173,4	675009	2413403	02222X0032	In Database	NO DATA	NO DATA
14-3795-	Extension	CERNEUX	CER-103	TOTAL EXPLO	12-juil-86	24-août-86	2839	KEUPER INFERIEUR	163,03	167,2	673225	2414455	02222X0033	In Database	NO DATA	NO DATA
14-3946-	Exploration secondaire	CERNEUX	CER-102	TOTAL EXPLO	18-janv-86	31-mars-86	2970	KEUPER INFERIEUR	165,3	169,5	669060	2414741	02221X0042	In Database	NO DATA	NO DATA
14-3930-	Exploration secondaire	CERNEUX	CER-x20	TOTAL EXPLO	21-oct-85	07-janv-86	3005	KEUPER INFERIEUR	155,7	159,9	667454	2418010	02221X0064	In Database	NO DATA	NO DATA
14-3313-	Exploration	CHAILLY	CH101	ERAP	22-avr-67	06-juil-67	2591	SOCLE	78,8	81,8	621994	2386077	02586X0082	NO DATA	NOT DESCRIBED	DESCRIBED
14-3827-	Extension	CHARMOTTES	CHM 4	ESSOREP	27-juin-85	31-juil-85	2708	KEUPER	115	123	645647	2393208	02591X0091	In Database	DESCRIBED	NO DATA
14-3691-	Exploration	CHARMOTTES	CHM 1	ESSOREP	21-juin-84	05-août-84	3000	SOCLE	113,5	119,5	648768	2393125	02592X0077	In Database	DESCRIBED	NO DATA
14-3787-	Extension	CHARMOTTES	CHM-3	ESSOREP	14-janv-85	21-févr-85	2680	KEUPER	120,8	123,8	647161	2391278	02592X0066	In Database	NO DATA	NO DATA
14-3800-	Exploration	CHAMPOTRAN	CHN-1	ESSOREP	07-avr-85	06-mai-85	2860	SOCLE METAMORPHIQUE	133,2	141	656602	2411920	02213X0035	In Database	NOT DESCRIBED	DESCRIBED
14-4353-	Exploration	CHAMPROSE	CHO-1	ESSOREP	04-déc-90	27-déc-90	2433	KEUPER SUP.	114,2	118,9	636601	2416003		In Database	NO DATA	NO DATA
14-4357-	Exploration	CLOS FONTAINE	CLF-1	SNEA(P)	22-déc-90	17-janv-91	2659	KEUPER INFERIEUR	128,8	135,68	648824	2400497	02216X0031	In Database	NO DATA	NO DATA
14-3560-	Exploration	CHALNOY	CNY 1	ESSOREP	03-avr-83	10-mai-83	2515	KEUPER	93	99	634422	2396756	02584X0030	NO DATA	NOT DESCRIBED	DESCRIBED
14-4052-	Exploration	COUBERT	COB-1D	TOTAL EXPLO	24-août-86	24-sept-86	2547	SOCLE METAMORPHIQUE	95,03	104,17	627208	2407529	02207X0064	In Database	NO DATA	NO DATA
14-4374-	Exploration	CONQUILLIE	CQL-1	TOTAL EXPLO	26-mars-91	26-avr-91	2746	KEUPER INFERIEUR	159,8	164,1	664774	2407734	02218X0029	In Database	NO DATA	NO DATA
14-4005-	Exploration	ESTERNAY	ESY-1	TOTAL EXPLO	03-juil-86	12-août-86	2671	KEUPER SUP.	167	176,2	690450	2415164	02224X0080	In Database	NO DATA	NO DATA
14-4006-	Exploration	ETANCON	ETC-1	ESSOREP	14-avr-86	03-mai-86	2693	KEUPER INFERIEUR	116,4	124	644602	2389542	02595X0055	In Database	NO DATA	NO DATA
14-3712-	Exploration	FRESNES	FRS-1	ESSOREP	23-août-84	01-oct-84	2664	KEUPER INFERIEUR	98,5	106	648377	2370715	02952X0159	In Database	NO DATA	NO DATA
14-4459-	Exploration	GRAND BREAU	GDB-1D	ELF A.P.	09-oct-95	07-nov-95	2563	KEUPER MOYEN A SUP.	111,7	118,4	645344	2406579	02215X0042	In Database	NO DATA	NO DATA
14-4346-	Exploration	GLAIRET	GLT-1	ESSOREP	09-nov-90	11-déc-90	3220	KEUPER INFERIEUR	158,4	165,4	657862	2435694	01853X0026	In Database	NO DATA	NO DATA
14-3815-	Exploration	HEURTAULT	HEU-1	ESSOREP	15-juin-85	07-juil-85	2813	KEUPER INFERIEUR	142,3	147,3	661129	2394652	02594X0088	In Database	DESCRIBED	NO DATA
14-3445-	Exploration	HEURTEBISE	HTE 1	ESSOREP	27-avr-79	24-mai-79	2715	SOCLE	101,3		642024	2394423	02591X0085	NO DATA	DESCRIBED	DESCRIBED
14-4292-	Développement	ILE DU GORD	IDG-5D	PETROREP	26-avr-90	09-mai-90	2618	KEUPER	58,47	66,57	630687	2435076		In Database	NO DATA	NO DATA
14-3897-	Exploration	IVERNY	IVY-1D	ESSOREP	19-oct-85	03-déc-85	2944	KEUPER INFERIEUR	104,7	112,3	645169	2397843	02591X0094	In Database	DESCRIBED	NO DATA
14-4225-	Exploration	JANVRY	JAY-1	ESSOREP	15-nov-88	13-déc-88	2998	KEUPER INFERIEUR	152	159,6	677974	2401792	02226X0055	In Database	NO DATA	NO DATA
14-4272-	Extension	LA CHARBONNIERE	LCH-1D	ESSOREP	26-sept-89	21-oct-89	2910	KEUPER SUP.	124,5	132	631388	2429502	01847X0022	In Database	NO DATA	NO DATA
14-3877-	Exploration	L'EPINEUSE	LEP-1	ESSOREP	23-août-85	27-sept-85	2995	KEUPER INFERIEUR	144,4	152,2	650582	2429620	01856X0024	In Database	NO DATA	NO DATA
14-3641-	Exploration	LA SABLIERE	LSB-1	ESSOREP	03-sept-83	23-sept-83	2528	SOCLE	103	109	638662	2405879	02208X0064	In Database	NO DATA	NO DATA
14-4398-	Exploration	MONTBARDON	MBN-1	TOTAL EXPLO	10-sept-91	02-oct-91	2600	KEUPER INFERIEUR	124,5	128,8	647399	2422573	01856X0027	In Database	NO DATA	NO DATA
14-3999-	Exploration	MONTLEVEE	ME-101	ESSOREP	05-mai-86	31-mai-86	3099	KEUPER INFERIEUR	156	164	647218	2435355	01852X0048	In Database	NO DATA	NO DATA
14-3613-	Exploration	MELARCHEZ	MEZ-1	ESSOREP	30-mai-83	18-juil-83	3193	KEUPER INFERIEUR	140	146	662355	2430161		In Database	NO DATA	NO DATA
14-3786-	Exploration	MALNOUE	MLN-1	ESSOREP	05-avr-85	20-mai-85	2960	KEUPER INFERIEUR	139,5	147,3	662037	2418989	02214X0031	In Database	NOT DESCRIBED	DESCRIBED
14-4449-	Exploration	NESLES	NSL-1	ELF A.P.	02-mai-95	06-juin-95	2483	KEUPER MOYEN A SUP.	107,06	113,76	646725	2412083	02212X0030	In Database	NO DATA	NO DATA
14-4443-	Exploration	PEZARCHES	PZH-1	ELF A.P.	05-févr-94	03-mars-94	2546	KEUPER SUP.	114,5	119,7	648810	2417254	02212X0031	In Database	NO DATA	NO DATA
14-3811-	Exploration	RACHEE	RAC-1	ESSOREP	09-mars-05	29-mars-05	2800	KEUPER INFERIEUR	136,5	143.20	654077	2395953	02592X0076	NO DATA	DESCRIBED	DESCRIBED
14-3931-	Extension	RACHEE	RAC-3	ESSOREP	10-déc-85	27-déc-85	2636	KEUPER	135	143	650018	2396841	02592X0076	In Database	NO DATA	NO DATA
14-3620-	Exploration	St LAZARE	SLZ-1	ESSOREP	10-nov-87	08-déc-87	2940	KEUPER INFERIEUR	141,8	147,8	658224	2421119	01857X0037	In Database	NO DATA	NO DATA
14-4233-	Exploration	St MARTIN EN BIERE	SMT-1D	SNEA(P)	06-déc-88	08-janv-89	2375	KEUPER INFERIEUR	75,4	82,28	617506	2383309	02585X0099	In Database	NO DATA	NO DATA
14-3503-	Exploration	St HILLIERS	STH-1	ESSOREP	03-sept-81	09-oct-81	2815	KEUPER INFERIEUR	160	166	668771	2403524	02225X0037	In Database	NO DATA	NO DATA
14-3685-	Exploration	SIVRY	SVY-1	TRITON FRANCE	09-juin-84	18-juil-84	2500	SOCLE	91	96	632660	2392015	02583X0083	In Database	NOT DESCRIBED	NO DATA
14-4131-	Exploration	VIGNOLLES	VGN-1D	ESSOREP	24-déc-87	31-janv-88	2620	KEUPER	105,66	111,03	626655	2415772	02203X0100	In Database	NO DATA	NO DATA
14-3810-	Exploration	VILLARCEAUX	VIX-1	ESSOREP	17-juin-85	24-juil-85	2675	KEUPER INFERIEUR	108,5	116	649672	2414254	02212X0026	In Database	DESCRIBED	NO DATA
14-4311-	Exploration	VOULZIE	VLZ-1	ESSOREP	24-mai-90	13-juin-90	2815	KEUPER INFERIEUR	125	133	670076	2393228	02601X0139	In Database	NO DATA	NO DATA
14-3417-	Exploration	VULAINES	VUS-1	ESSOREP	30-nov-77	16-févr-78	3057	SOCLE CRISTALLIN	135	138,6	665090	2397544	02594X0074	In Database	DESCRIBED	DESCRIBED
14-3966-	Exploration secondaire	VULAINES	VUS-3	ESSOREP	21-mars-86	17-avr-86	2755	KEUPER INFERIEUR	134	141	664585	2395289	02594X0085	In Database	NOT DESCRIBED	DESCRIBED
14-4002-	Exploration	VAUXPLEURS	VXP-1	ESSOREP	10-avr-86	02-mai-86	2631	SOCLE REMANIE	127,7	135	647477	2425614	01856X0026	In Database	NO DATA	NO DATA
14-1977-	Exploration	VILLEFERMOY	VY 101	RAP	17-déc-60	18-janv-61	1817,2	DOGGER SUPERIEUR	124		641148	2390427	02591X0001	NO DATA	DESCRIBED	NO DATA

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8.2 Annexe 2 – Sedimentological facies and Faciès associations

i) **Upper offshore domain:** Only represented by one facies, this depositional environment is associated to the deepest environments met along cores. Marls are the main facies which is sometimes composed of some bioclasts and brachiopods. This facies will be associated to a high GR on well logs. This environment is associated to a low hydrodynamic influence where sedimentation is mainly driven by bottom currents and sedimentary flux from the shelf.

Tableau 8-1: Facies description and facies association classification for upper offshore depositional environment

Lithofacies	Dunham texture	Structures	Grain size / sorting	Non-skeletal elements	Skeletal elements	Facies Association	Depositional Environment
F1a	Marls	Highly bioturbated	-	-	Brachiopods	**FA1a: Marls**	**Upper offshore**

ii) **Lower offshore domain.** Represented by three different facies regrouped into two facies association, this environment is at the gate of the sedimentation from shelf. Mainly influenced by sedimentary flux from the ramp, main facies are a commonly composed of clay and skeletal elements which mainly developed on the outer ramp domain. Bioturbation is commonly visible as well.

Tableau 8-2: Facies description and facies association classification for lower offshore depositional environment

Lithofacies	Dunham texture	Structures	Grain size / sorting	Non-skeletal elements	Skeletal elements	Facies Association	Depositional Environment
F2a	Mudstone	Highly bioturbated	clay	clay	Foraminifers, undifferentiated bioclast, brachiopods	**FA2a: Clayey mudstone**	**Lower offshore**
F2b	Wackstone	Highly bioturbated	silt	clay, silts	Brachiopods, oyster shells, bryozoan, echinoid	**FA2b: Bioclastic wackstone alternating with marls / mudstone**	
F2c	Mudstone / marls	-	clay	clay, silts	Foraminifers, undifferentiated bioclast, brachiopods		

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iii) Outer ramp domain. Two facies associations represent this depositional environment with five sedimentary facies. This environment represent the distal part of the carbonate ramp system with the onset of bioclastic grainstone, some clay laminations and presence of ooids potentially flushed from the middle ramp / shoal domains. Hydrodynamism is driven by drastic events like storm and currents from ramps. Bioturbation could be common and skeletal elements represent different environments like lagoon to distal part. This validate potential currents, which export Lagoonal elements into the distal part of the ramp.

Tableau 8-3: Facies description and facies association classification for outer ramp depositional environment

Lithofacies	Dunham texture	Structures	Grain size / sorting	Non-skeletal elements	Skeletal elements	Facies Association	Depositional Environment
F3a	Mudstone / Wackstone	-	Fine to very fine sand	ooids	Bivalves, Echinoderm, Crinoids, Gastropods, oyster shell	**FA3a: Clayey calcareous mudstone / Wackstone**	**Outer ramp**
F3b	Packstone	-	Fine	extraclast	corals clast, crinoids, brachiopods, oyster	**FA3b: Clayey Packstone with undifferentiated bioclast**	
F3c	Wackstone / Packstone	Planar lamination	Very fine	thin clay lamination	bioclast, echinoids, bryozoan		
F3d	Packstone / Grainstone	Bioturbated	Fine/ clay cement / well sorted	Ooids, Oncoids	bioclast, bryozoan		
F3e	Grainstone	Bioturbated	Fine / poorly sorted	ooids, clay	bivalves		

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iv) **Shoal / middle ramp domain.** Represented by five facies association regrouping eight different sedimentary facies, this depositional environment represent the most developed interval in the reservoir complex. Main target for the CO_2 storage, this environment is mainly influenced by strong currents as tidal and wave which let the development of sedimentary dunes. The high number of cross-stratification, and erosive surfaces highlighted by bioclastic lags indicated the sting hydrodynamism of the environment and the interpretation of dunes onset. Composition of these dunes vary from ooids to bioclastic dominated. Ratio between these non-skeletal and skeletal elements is important for reservoir properties. This part will be developed in the section 7.5. Details concerning facies, elements composition is proposed in the table below.

Tableau 8-4: Facies description and facies association classification for shoal/middle ramp depositional environment

Lithofacies	Dunham texture	Structures	Grain size / sorting	Non-skeletal elements	Skeletal elements	Facies Association	Depositional Environment
F4a	Packstone / Grainstone	bioturbation	sand / poorly sorted	ooids	bioclast, brachiopods, bivalves	**FA4a: Oo-bioclastic Packstone / Grainstone with cross-stratification**	**Shoal / middle ramp**
F4b	Packstone / Grainstone	cross-stratification	sand, finning upward	Pelloids	bryozoan, oyster clast, gastropods, crinoids, bivalves		
F4c	Packstone / Grainstone	-	poorly sorted	black extraclast	corals clast, crinoids, brachiopods, oyster	**FA4b: Bioclastic Grainstone**	
F4d	Grainstone	cross-stratification	sand / well-sorted	-	bioclast, bivalves clast		
F4e	Grainstone	planar structures / fossil traces	sand / well sorted	ooids, clay clasts	bioclast, bryozoan, echinoids	**FA4c: Oo-bioclastic grainstone. From Ooid to bioclastic dominated Grainstone**	
F4f	Grainstone	cross-stratification	sand / well sorted	ooids, clay clasts, black gravel	bioclast, bryozoan, echinoids, foraminifers		
F4g	Grainstone	cross-stratification	sand, very well sorted	Ooids	-	**FA4d: Ooid Grainstone**	
F4h	Rudstone	-	coarse, very coarse sand	ooids, extraclast	bioclast, corals clast, oyster shells, brachiopods	**FA4e: Oo-bioclastic Rudstone**	

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v) **Back-shoal domain.** Described and interpreted along sedimentary cores, this depositional environment is represented by five sedimentary facies regrouped into two facies associations. Main skeletal elements composing these facies and specific surfaces as performed one indicate the mix between strong sedimentary event and a stop of the sedimentation. Coupled with some bioturbations and specific elements as algae, this environment is interpreted as the sedimentation occurring behind shoal line, probably due to import of outer and middle ramp elements into lagoon environment during storm events.

Tableau 8-5: Facies description and facies association classification for back-shoal depositional environment

Lithofacies	Dunham texture	Structures	Grain size / sorting	Non-skeletal elements	Skeletal elements	Facies Association	Depositional Environment
F5a	Grainstone		medium / finning upward	Oncoids	undifferentiated bioclast	**FA5a: Oo-pello-oncoidal Grainstone with bioclast.**	**Back-shoal**
F5b	Grainstone	perfored surfaces	Medium to fine	Pelloids, ooids, oncoids,	bryozoan, bivalves, foraminifers		
F5c	Packstone / Grainstone		fine	Pelloids	bioclast, gastropods, brachiopods	**FA5b: Pelloidal Packstone**	
F5d	Packstone	bioturbation	Medium to fine / thickening upward	Pelloids	bioclast, brachiopods, bivalves		
F5e	wackstone	Planar lamination (traction)	fine		echinoids, rounded bioclast, bivalves		

vi) **Tide-dominated lagoon domain.** Five facies regrouped into two facies association represent this depositional environment. Main elements identified indicated a shallow water environment with the presence of oncoids, milioles, and pelloids. However, grainstone and packstone texture, coupled with cross-stratification, indicate as well presence of string currents, interpreted as tidal one. Consequently, this environment indicate that locally, grainy facies are developed into the Lagoonal domain, which let the reworking of shallow element into the middle and outer ramp.

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Tableau 8-6: Facies description and facies association classification for tide-dominated lagoon depositional environment

Lithofacies	Dunham texture	Structures	Grain size / sorting	Non-skeletal elements	Skeletal elements	Facies Association	Depositional Environment
F6a	Grainstone	Dunes	sand to granule / well sorted	pelloids	undifferentiated bioclast	**FA6a: Bioclastic grainstone with ooids, oncoids and pellets**	**Tidal-dominated lagoon**
F6b	Grainstone	-	sand to granule / well sorted / finning upward	undifferentiated black granules, few ooids	gastropods, bryozoan, brachiopods, bivalves		
F6c	Packstone / Grainstone	bioturbation	sand to granule / poorly sorted	oncoids, black pelloids,	gastropods, bryozoan, brachiopods, bivalves,	**FA6b: Pello-oncoid packstone**	
F6d	Wackstone / Packstone	bioturbation	sand / well sorted	Oncoids	crinoids, brachiopods, bivalves		
F6e	Wacktone	-	sand	Pelloids, oncoids, black gravels	gastropods, corals		

vii) **Lagoon domain.** Representing the shallowest depositional environment identified on cores, this domain is composed of seven sedimentary facies regrouped into three facies association. Main difference is on calcareous texture with the presence or not of a micritic cement. Presence of strong bioturbations, pelloids, oncoids and milioles indicate a shallow water environment. Large size oncoids (centimetres) support this interpretation with a protected area from strong currents which let the development of this specific element.

Tableau 8-7: Facies description and facies association classification for lagoon / inner ramp depositional environment

Lithofacies	vDunham texture	Structures	Grain size / sorting	Non-skeletal elements	Skeletal elements	Facies Association	Depositional Environment
F7a	Wackstone / Packstone	bioturbation	Fine to pebble	pelloids, oncoid,	bivalves, brachiopods, milioles	**FA7a: Onco-pelloid wackstone with milioles**	**Lagoon / inner ramp**
F7b	Wackstone / Packstone	bioturbation	Fine to pebble	black extraclast, pelloids, rare ooids,	gastropods, bioclast, milioles		
F7c	Wackstone	bioturbation	Pebble	Oncoids	brachiopods, gastropods	**FA7b: Oncoidal wackstone**	
F7d	Mudstone / Wackstone	-	Fine to coarse	Oncoids	-		
F7e	Grainstone	bioturbation	Fine to medium / poorly sorted	Oncoids, gravels, pelloids,	bivalves	**FA7c: Onco-pelloidal grainstone with milioles and green algae**	
F7f	Grainstone	-	very fine / very well sorted	pelloids	green algae, gastropods, milioles		
F7g	Grainstone	bioturbation	fine	Oncoids	bioclast		

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8.3 Annexe 3 – Sequence stratigraphic scheme

8.3.1 Second order scale

At the second order scale, the complex reservoir is divided into one and an half cycle. From the Top_Bajocian, a first long prograding stage is observed and associated to the Bajocian-Bathonian Cycle. This half cycle comprise the succession of Marne à *Ostrea acuminate*, Oolithe Blanche (Reservoir 1) and Comblanchien (Semi-permeable 1) formations. Top of the Comblanchien formation is considered as a Maximum Regressive Surface. Then a second full cycle, associated to Callovian-Oxfordian cycle is recorded. This sequence comprise the transgressive formation of the Dalle Nacrée (Reservoir 2), the Callovo-Oxfordian Marls (Caprock 1) and the Oxfordian Limestone (Caprock 2).

8.3.2 Third-order scale

At the third order scale, three and a half cycles are proposed. The reservoir 1 is divided into two parts (one and an half cycle), delimited by the Bt10 MFS, associated to the ZigZag Zone proposed by Gaumet (1997). This MFS divide the reservoir into a prograding stage, followed by an aggrading stage. The prograding stage is associated to a Highstand System Tract (HST) with a positive accommodation rate and a sedimentation rate superior to the accommodation (A>0 and S>A). Top of the HST-1 is delimited by a MRS located at the top of interpreted middle ramp facies. After a small transgressive stage delimited at the top by the Bt10 MFS, the Aggradational stage take place and is associated to a Highstand System Tract (HST-2). The transition with the followed Comblanchien formation, associated to Lagoonal facies, is interpreted as the onset of a Lowstand System Tract (LST-2) where S>A and accommodation rate is negative.

8.3.3 High-frequency cycle

At the High frequency scale prograding and aggrading stage of the reservoir are respectively divided in 2 and 4 parts. Progradation 1 and 2 are delimited by the bt7 Maximum flooding surface. Aggradation 1 to 4 are divided, in stratigraphic order, by, Bt12, Bt17 and Bt19 Maximum Flooding surfaces. After the delimitation of the Comblanchien LST-1 and the Dalle Nacrée HST, it is proposed to divided Caprock into 4 parts where MRS are interpreted at the top of calcareous intervals and MFS in the middle of Marls / argillaceous intervals. Consequently, Caprock-1 interval is divided into three and an half Prograding / retrograding cycles and Caprock-2 is associated to the last prograding stage of the storage complex.

8.4 Annexe 4 – 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 three 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 neighboring traces throughout the 3D seismic data (Figure)).

(2) **3D RGT Model Computation** - The second step consists of calculating a 3D RGT 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).

(4) **Sequence stratigraphy model computation** – this fourth part concern the identification and definition of seismic stratigraphy surfaces and seismic units. This last stage follow the basics of the seismic stratigraphy interpretations methods developed in the 70's by Mitchum et al., 1977a, 1977b ; Vail and Mitchum, 1977 and Vail et al., 1977a. Seismic unconformities are defined by the determination of stratal terminations as downlap, onlap, toplap, erosional truncation, and offlap, are defined. Each seismic unconformity define 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". Thanks to the Horizon stack computation, all chronostratigraphic surfaces are mapped and let us to define major unconformities.

Description of the methodology for petrophysical characterizations, time to depth conversion, gravimetric survey, passive surveys, electrofacies methods, etc.

In the main report we should only include results with brief descriptions.

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8.5 Annexe 5 – Horizons classification

Stratigraphy	MARKER	Lithostratigraphic unit	Reservoir Unit	Available as
Cretaceous	Top_Cenomanian			Well Marker
	Top_Alb. Clay			Well Marker
	Top_Alb. Sand			Well Marker
	Top_Albo-Aptian			Well Marker
	Top_Barremian			Well Marker, 3D horizon
Jurassic	Top_Purbeckian			Well Marker, 3D horizon
	Top_Portlandian			Well Marker, 3D horizon
	Top_Kimmeridgian			Well Marker, 3D horizon
	Top_Oxfordian_Sup	Oxfordian Limestone	Top Caprock 2	Well Marker, 3D horizon
	Top_Oxfordian-Inf	Callovo Oxfordian Marls	Top Caprock 1	Well Marker, 3D horizon
	Ca26_vf	Dalle Nacree	Top Reservoir 2	Well Marker, 3D horizon
	Ca24_vf	Comblanchien, top Bathonian		Well Marker, 3D horizon
	Sb-Comb_vf	Oolithe Blanche	Top Reservoir 1	Well Marker
	Bt10_vf			Well Marker, 3D horizon
	Bj1_vf	Top Bajocien	Base Reservoir 1	Well Marker, 3D horizon
	Top_Aalenian			Well Marker, 3D horizon
	Top_Toarcian			Well Marker, 3D horizon
	Top_Lias-Middle			Well Marker, 3D horizon
	Top_Rhetian			Well Marker

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