A site selection methodology for CO2 underground storage in deep saline aquifers: case of the Paris Basin

Sandrine Grataloup, Didier Bonijoly, Etienne Brosse, Rémi Dreux, Daniel Garcia, Vladimir Hasanov, Marc Lescanne, Patrick Renoux, Alain Thoraval

Energy Procedia, 2009, 1(1), 2929-2936, doi:10.1016/j.egypro.2009.02.068

A site selection methodology for CO_2 underground storage in deep saline aquifers: case of the Paris Basin

Sandrine Grataloup[(1)]*, Didier Bonijoly[(1)], Etienne Brosse[(2)], Rémi Dreux[(3)], Daniel Garcia[(4)], Vladimir Hasanov[(5)], Marc Lescanne[(6)], Patrick Renoux[(7)], Alain Thoraval[(8)]

(1) *BRGM, 3 avenue Claude Guillemin, BP 36009, 45060 Orléans cedex 2, France*
(2) *Institut Français du Pétrole, 1 et 4 avenue de Bois-Prau, 92852 Rueil-Malmaison Cedex, France*
(3) *Gaz De France, 361 avenue du Président Wilson, BP33, 93211 Saint-Denis La Plaine Cedex, France*
(4) *Ecole Nationale Supérieure des Mines de Saint Etienne, Centre SPIN ; Département GENERIC ; 158 Cours Fauriel ; 42023 Saint-Étienne Cedex 2, France*
(5) *Air Liquide, 1 Chemin de la Porte des Loges, 78354 Jouy-en-Josas, France*
(6) *TOTAL SA, Avenue Larribau, 64018 Pau cedex, France*
(7) *Géostock, 7 rue E. et A. Peugeot, 92563 Rueil Malmaison, France*
(8) *Institut National de l'Environnement Industriel et des Risques, Ecole des Mines de Nancy, Parc de Saurupt, 54042 Nancy, France*

Abstract

Site selection is a fundamental step, which can condition the success of a CO_2 geological storage. A CO_2 storage has to gather several targets, which can be expressed through a list of criteria. In the proposed site selection methodology, these criteria can be classified into "killer criteria" and "site-qualification criteria", whose combinations allow identifying potential sites and the most appropriate one(s).
This multicriteria methodology is applied on the PICOREF study area, located in the Paris Basin, on which potential site(s) in deep saline aquifers are investigated.

Keywords:

CO2 geological storage; Site selection; Saline aquifer; Paris Basin; PICOREF

I. Introduction

The PICOREF project *(Pilote pour l'Injection de CO2 dans les Réservoirs géologiques, En France*, 2006-2008) aimed, in particular, at (i) developing a methodology of site selection for CO_2 geological storage in deep saline aquifers and (ii) studying the injection of CO_2 in specific contexts of the Paris Basin where data were available, ie the depleted oil-field of Saint-Martin de Bossenay and the deep saline aquifers of a limited area in the south-east of Paris [1].
The Paris Basin is the largest onshore sedimentary basin in France and occupies a large part of its northern half (Figure 1). It is a stable intracratonic basin, mainly filled with Mesozoic and Cenozoïc sediments, up to about 3000 m in the central part, close to the Paris city, and lying unconformably on a Palaeozoic basement [2].
The European project Gestco [3] had previously identified two deep saline aquifers as possible candidates for CO_2 storage in the Paris Basin: Dogger carbonates and Triassic sandstones (Figure 1). These multi-layers aquifers had been investigated more precisely on the PICOREF

* Auteur à qui la correspondance devait être adressée : s.grataloup@brgm.fr

Energy Procedia, 2009, 1(1), 2929-2936, doi:10.1016/j.egypro.2009.02.068

Sector, located south-east of Paris (about 70km x 70km, in red on Figure 1), in order to find and characterise potential sites for CO_2 storage at a pilot scale (injection around few hundreds of thousands tons to a million tons) and study the impact of a CO_2 injection.

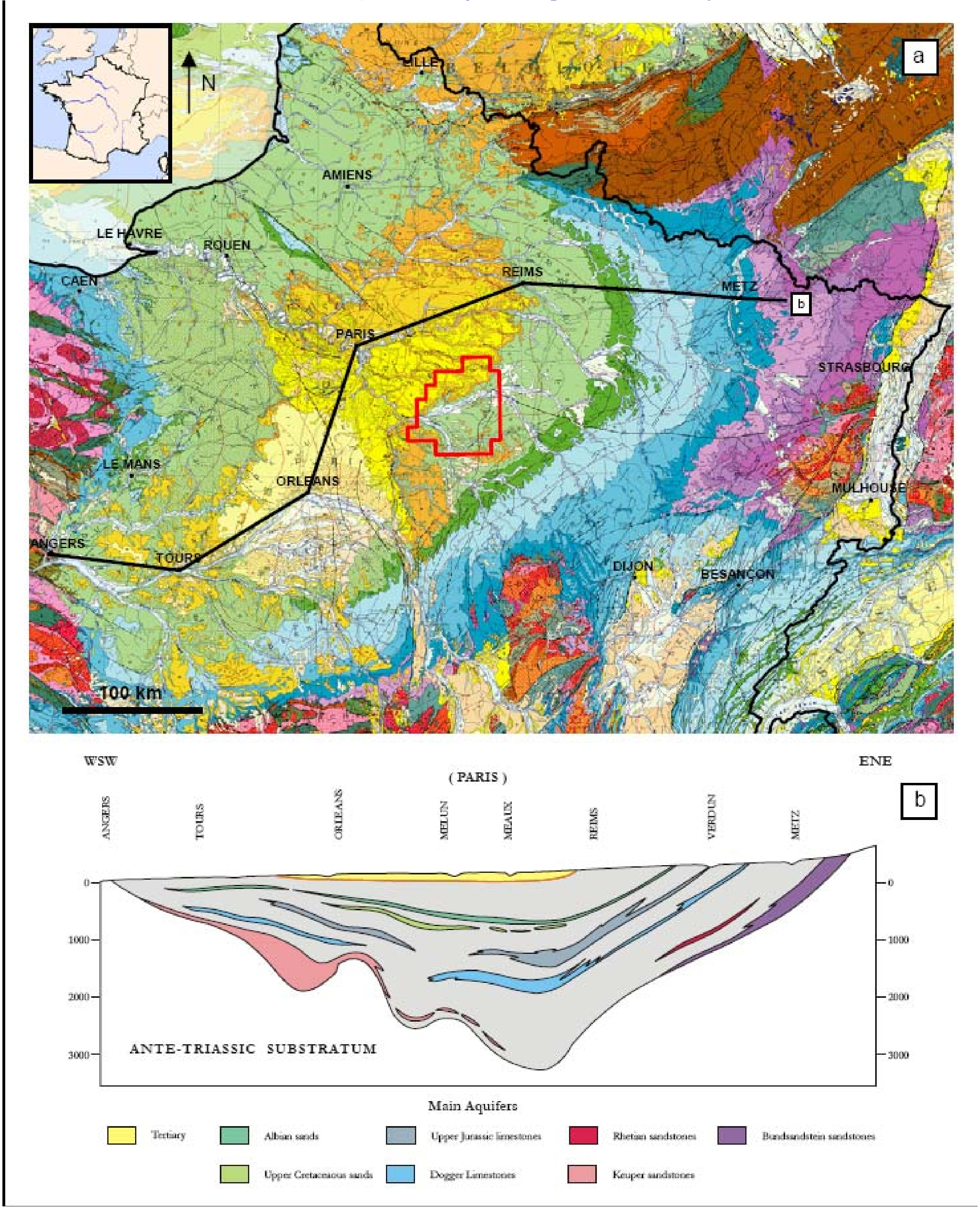

Figure 1: a) Geological map of the Paris Basin and localization of the PICOREF Sector (in red) and b) schematic cross-section of the main aquifer units on a WSW-ENE transect (modified from [4] and [3]).

The identification of a potential site adapted to pilot scale CO_2 storage inside this Sector has followed a two steps process [5]:

- development of a site selection methodology for deep saline aquifers, inspired by existing screening processes [6] [7],

- extensive data compilation, with about 1100 km seismic reprocessing, geological reinterpretation of the whole PICOREF Sector, and ultimately application of the selection methodology [5].

II. Site selection methodology

Site selection is a fundamental step that conditions the success of a CO_2 storage operation [8]. Once basin or regional scale screening have been achieved [6] [7], potential storage sites have to be identified.

Unlike depleted oil or gas fields, which are localized and generally well-known, potential aquifer sites have to be characterised from raw geological data before any ranking is possible. Hence, the site selection process is particularly time and expertise consuming in the case of storage in aquifers.

As for basin screening, which can be performed taking into account a certain number of factors [6] [7], the site selection process is based on the combination of several criteria, which correspond to quantitative or qualitative expressions of storage key principles.

II.1. CO_2 storage objectives and site selection criteria

The selection of an appropriate CO_2 geological storage site must meet four priority objectives [5]:

- storage optimization, in terms of capacities and injectivity (1),
- risks minimization (2),
- respect of regulation, environmental constraints, existing land-use and underground-use (3),
- consideration of economic and social aspects (4).

These goals can be expressed through a certain number of simple criteria, which have already been documented in literature [6] [7].

Table 1 presents the criteria which are useful for site selection. Data used for site identification can come from documents' compilations, new data analysis or data acquisition.

(1) Storage optimization aims at finding a site with maximal storage volumes, in which injection can be performed in favorable conditions. These characteristics can be estimated, in a first approach, through "capacity" and "injectivity" parameters. The capacity of a site is indeed a function of the available pore space, which is itself proportionnal to porosity and thickness of the aquifer and to the trap dimensions. In capacity appraisal, efficiency coefficients do also play a role [9]. They can be estimated from detailed studies of the sediments and numerical simulations. Injectivity can be defined as the rate at which CO_2 will be injected before pressure build-up goes beyond given threshold values. It depends on aquifer permeability, thermodynamics conditions, which determine CO_2 density and viscosity, reservoir thickness available for injection, and mechanical properties of both reservoir and cap-rock.

(2) Risks minimization aims at reducing as much as possible the number of potential leakage factors on the storage area. It may be expressed through the storage confinement by the seal itself (thickness, permeability, lateral continuity) or by secondary seals, through the number of potential leakage pathways (abandoned wells, faults, potential exutories), through the different hazards that can affect the storage area like seisms or landslides or through the minimization of risks targets (population density on urban areas, industrial zones...).

(3) The respect of regulation, environmental constraints, existing land-use and underground-use aims at integrating the CO_2 storage in its context and avoiding any damaging or illegal consequences on storage environment. Conflicts of use (land surface or underground) can indeed dismiss CO_2 storage operations.

(4) The consideration of economic and social aspects include the analyses of costs (re-use of existing infrastructures, building of new installations...) and social constraints such as

Energy Procedia, 2009, 1(1), 2929-2936, doi:10.1016/j.egypro.2009.02.068

population acceptance for instance. The costs of operation are directly linked to injectivity potential and monitoring requirements.

Table 1: Criteria to take into account for a site selection process (from [5]).

Objective		*Criteria*	*Object/area*
Storage optimization	*Storage capacity*	(total, effective) porosity	Target aquifer
		(total, net) thickness	Target aquifer
		Trap dimensions	Target aquifer and cap-rock
		Pressure and temperature conditions	Target aquifer
	injectivity	(relative) permeability	Target aquifer
		(total, effective) porosity	Target aquifer
		Pressure and temperature conditions	Target aquifer
		Injection thickness	Target aquifer
		Reservoir failure ((pressure build-up)	Target aquifer
		Entry pressure (pressure build-up)	Cap-rock
Risks minimization	*Storage confinement*	thickness	Cap-rock
		Permeability, entry pressure	Cap-rock
		Lateral continuity	Cap-rock
		Entry pressure (pressure build-up)	Cap-rock
		Secondary containement system	overburden
	Leakage pathways	Abandoned wells	Target aquifer, cap-rock and overburden
		(conductive) faults	Target aquifer, cap-rock and overburden
		Exutories/migration pathways	Target aquifer, cap-rock and overburden
	Storage integrety	Seismic hazard	Storage area
		Landslides hazard	Storage area
	vulnerability	Vulnerability urban or industrial areas....	Storage area
Respect of regulation, and spatial constraints	*Environmental constraints*	Protected areas	Storage area
	Underground use	Existing exploitation of target aquifer	Storage area
	Land-use	Exploration or exploitation licenses	Storage area
Consideration of social and economic aspects	*Economic aspects*	Source-sink distance	Storage area and more
		Accessibility of site storage	Storage area and more
		Existing surface infrastructures	Storage area and more
		Surface and underground infrastructures to build	Storage area
	Social aspects	Population acceptance	Storage area and more

II.2. Site selection

The site selection step is based on the principle that previously listed criteria can be classified, depending on local context and objectives, into two categories: “killer criteria” and “site-qualification criteria” [5]. “Killer criteria” completely disqualify certain areas of the studied basin whereas “site-qualification criteria” allow ranking several potential sites according to their relevance compared to a given problematic (CO_2 volume to inject, limited budget...).
Site selection is a two-steps approach:

- meeting all “killer criteria” that defines potential sites locations after disqualified areas have been eliminated;
- combining the various “site-qualification criteria” allows to rank the previously obtained potential sites in according to their respective interest for one or the other of the objectives, and gives a way to choose the most appropriate site(s) in a given context.

The combination of killer criteria can be performed thanks to a GIS tool as soon as these criteria are expressed as Boolean “values” – possible storage or impossible storage. A GIS tool allows the simultaneous visualization of the different parameters, whose superposition delimitates potential zones for storage.
The analysis of site-qualification criteria can also be done following a GIS workflow if the number of criteria is limited or relatively easy to combine. They can be either qualitative through areas of validity, or quantitative through lines of iso-values. In case several parameters are difficult to combine, a system of classes and scores for each criterion – from least favourable to most favourable – can be used. Once each site has been characterised by such criteria classes, the mean of associated scores can measure the favourability of each site. This approach, already used in basin screening [10] could also be developed for site selection.
An important aspect of site-selection methodology is the variability of cases depending on projects issues and available data. Depending on local context and specific objectives, some of the criteria can belong to a category or the other. Moreover, according to the study context and data availability, only a part of listed criteria can be used to perform the site(s) identification. Characterisation of selection criteria can then be obtained from data compilations, new reprocessing and analyses or data acquisitions.

III. Application to the PICOREF Sector (Paris Basin)

III.1. General context

The methodology described above is applied to the to the Dogger aquifer of the Paris Basin in the PICOREF Sector (figure 1). On this area, numerous works have been achieved: outcrops studies, updating of the sedimentological models, compilation of petrophysical data, environmental synthesis, seismic and landslides hazards characterization, seismic reprocessing and interpretation, fault network revision, well data reinterpretations, 3D geological model, CO_2 injection simulations...
The main trapping mechanism for the Dogger aquifer would be hydrodynamic, as limestone layers gently dip at the Sector scale towards the north-west and as they are covered by a stratigraphic regional seal – the callovooxfordian clays and marls.
Moreover, a preliminary modelisation of CO_2 injection at a pilot scale – injection of 150 000 tons during four years – in the Dogger Formation has shown a plume radius of few kilometres [11]. This result gave an approximate size for sites, which have to be found on the Sector: a radius of about five kilometers was taken as reference.
The site selection process followed two steps: combination of killer criteria and the site-qualification criteria, according to the available data [5].

III.2. Combination of killer criteria

The considered “killer criteria” on this area are the following ones:

- depth of top Dogger; in order to operate with CO_2 in a supercritical state, injection has to be performed at depths below 800-1000 meters [8]; as the Dogger top on the Sector, is expected to be always deeper than 1000 meters, this criterion is not a killer criterion;
- underground use; no geothermal activity exists on the studied area and the exploited oil fields are included in the exploitation licences (next criterion);
- exploration or exploitation licences;
- natural protected areas;
- presence of major faults, which affect the whole sedimentary succession.

The combination of these criteria was done via a GIS tool (MapInfo software) and led to the identification of two potential sites by determining the areas where no excluding criterion exists (Figure 2): the first one, called West site, is located in the south-west part of the Sector and the second one, called East site, is close to the center of the Sector.

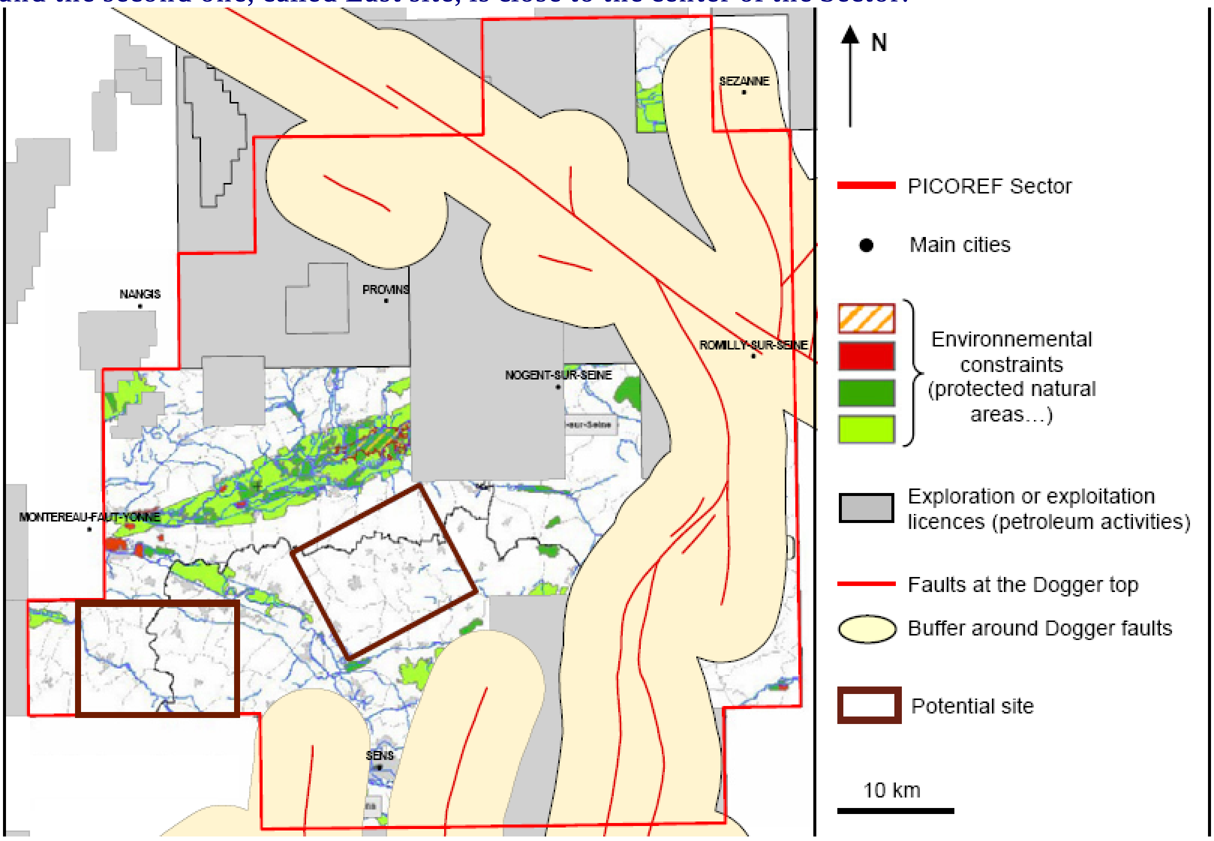

Figure 2: Result of the combination of the "killer criteria" on the PICOREF Sector – identification of potential sites (from [5]).

III.3. Site qualification criteria

To compare the two previously selected sites, site-qualification criteria have to be considered. The available sitequalification criteria are the following ones:

- thickness of the Oolithe Blanche Formation, the main aquifer unit of the Dogger, which is about 80 m on the east site whereas it is about 40 m on the west one (Figure 3);
- thickness of the callovo-oxfordian seal, which is similar over the two considered sites;
- number of abandoned wells, which is a little higher on the east site than in the west site;
- distance to CO_2 sources; at the Sector scale, several CO_2 sources could be available within a radius of 30 km around potential sites;

- seismic hazard, which is not a discriminating parameter since it is very low on the whole Sector;
- urban areas , which is not a discriminating parameter since there is no important urban areas;
- landslides hazards, which seem to have low to middle level on the both of the potential sites;

In this context, the criterion which appears the most relevant for discrimination between the two sites is the thickness of the Oolithe Blanche formation. On this basis, the site which has been chosen for modelling CO_2 injection in the Dogger aquifer is the East site [12].

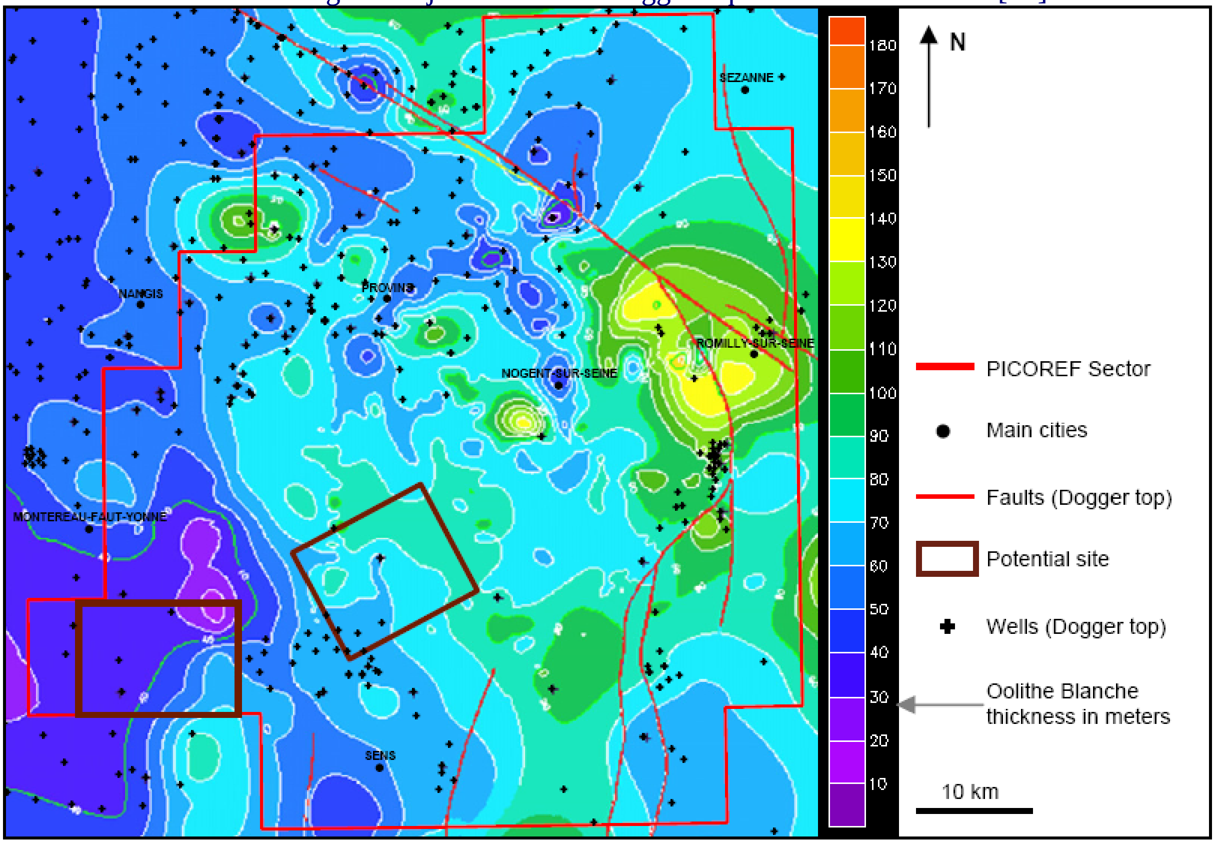

Figure 3: Comparison between the two potential sites – Oolithe Blanche thickness and existing wells at Dogger top (from [5]).

IV. Conclusion

Site selection is a crucial step in the CO_2 storage process. It is particularly essential for deep saline aquifers, in which knowledge and data are generally much less numerous than for depleted oil or gas fields.

This site-selection process can be performed thanks to a multicriteria approach. A list of criteria is proposed, according to the fundamental goals of CO_2 storage. These criteria can then be categorized in two types: “killer criteria” and “site-qualification criteria”. The combination of the killer criteria allows the delimitation of potential zones for CO_2 storage whereas combination of site-qualification criteria can provide a way to compare potential sites and then identify the most appropriate one in a given context.

Depending on local context, objectives and data availability, criteria used in this site selection process can change. Their qualitative or quantitative characterization can be provided by data compilations, new reprocessing and analyses or new data acquisitions.

This methodology has been applied on the PICOREF Sector, in the Paris Basin thanks to a GIS tool. It led to the determination of two potential areas, which have been then discriminated thanks to a site-qualification criterion.

Acknowledgements

PICOREF was a R&D project supported by the French National Research Agency and by a consortium of French companies, research institutions and academic laboratories. This project gathered the following companies: IFP, BRGM, GDF, Geostock, INERIS, TOTAL, ENSMP and Air Liquide.

References

[1] E. Brosse, G. de Smedt, D. Bonijoly, D. Garcia, S. Saysset, T. Manaï, A. Thoraval, S. Crepin, PICOREF : Towards an experimental site for CO_2 geological storage in the Paris Basin ? GHGT8 Conference papers, Trondheim, Norway. (2006) 5pp. www.ghgt8.no.

[2] J. Delmas, P. Houel, R. Vially, Paris Basin, Petroleum potential. IFP regional Report. (2002).

[3] D. Bonijoly, with the collaboration of J. Barbier, J.M. Matray, C. Robelin, C. Kervevan, D. Thierry, A. Menjoz, C. Coticheand B. Herbrich., Feasibility of CO_2 storage in geothermal reservoirs. Example of the Paris Basin, France. BRGM-CFG-ANTEA contribution to the GESTCO project. Fifth RTD Framework Programme Report BRGM/RP-52349-FR. (2003) 135pp. www.brgm.fr.

[4] BRGM, 1/1 000 000 geological map. Revised sixth edition (2003).

[5] S. Grataloup, D. Bonijoly, Projet PICOREF Une méthodologie de sélection de site en aquifére salin profond pour le stockage géologique de CO_2. Report BRGM/RP-56971-FR (2008) www.brgm.fr.

[6] S. Bachu, Sequestration of CO_2 in geological media: criteria and approach for site selection in response to climate change, *Energy Conversion and Management* **41** (9) (2000), pp. 953–970. [7] CO_2RC, Storage capacity estimation, site selection and characterisation for CO_2 storage projects. Cooperative Research Centre for Greenhouse Gas Technologies, Canberra. CO_2CRC report n RPT08-1001. (2008) 52pp. www.co2crc.com.au.

[8] IPCC, IPCC Special Report on carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change. Cambrige University Press, Cambridge, United Kingdom and New York. (2005) 431pp. www.ipcc.fr.

[9] DOE, Carbon sequestration atlas of the United states and Canada. Appendix B: methodology for development of geological storage estimates for carbon dioxide. (2008) pp. 115-132 www.netl.doe.gov.

[10] C.M. Gibson-Poole, S. Edwards, R.P. Langford, B. Vakarelov, Review of geological storage opportunities for carbon capture and storage (CCS) in Victoria. PESA Eastern Australasian Basins Symposium III, 455-473. (2008) pp455-473. www.co2crc.com.au.

[11] P. Durst, C. Kervévan, Modélisation 3D couplée chimie-transport de l'injection de CO_2 à l'échelle d'un site pilote en aquifére salin profond (Dogger, bassin de Paris). Report BRGM/RP-55667-FR. www.brgm.fr.

[12] P. Durst, C. Kervévan, Intégration de la topographie à la modélisation 3D couplée chimie-transport de l'injection de CO_2 à l'échelle d'un site pilote en aquifére salin profond (Dogger, bassin de Paris). BRGM Report in press. (2008) www.brgm.fr.