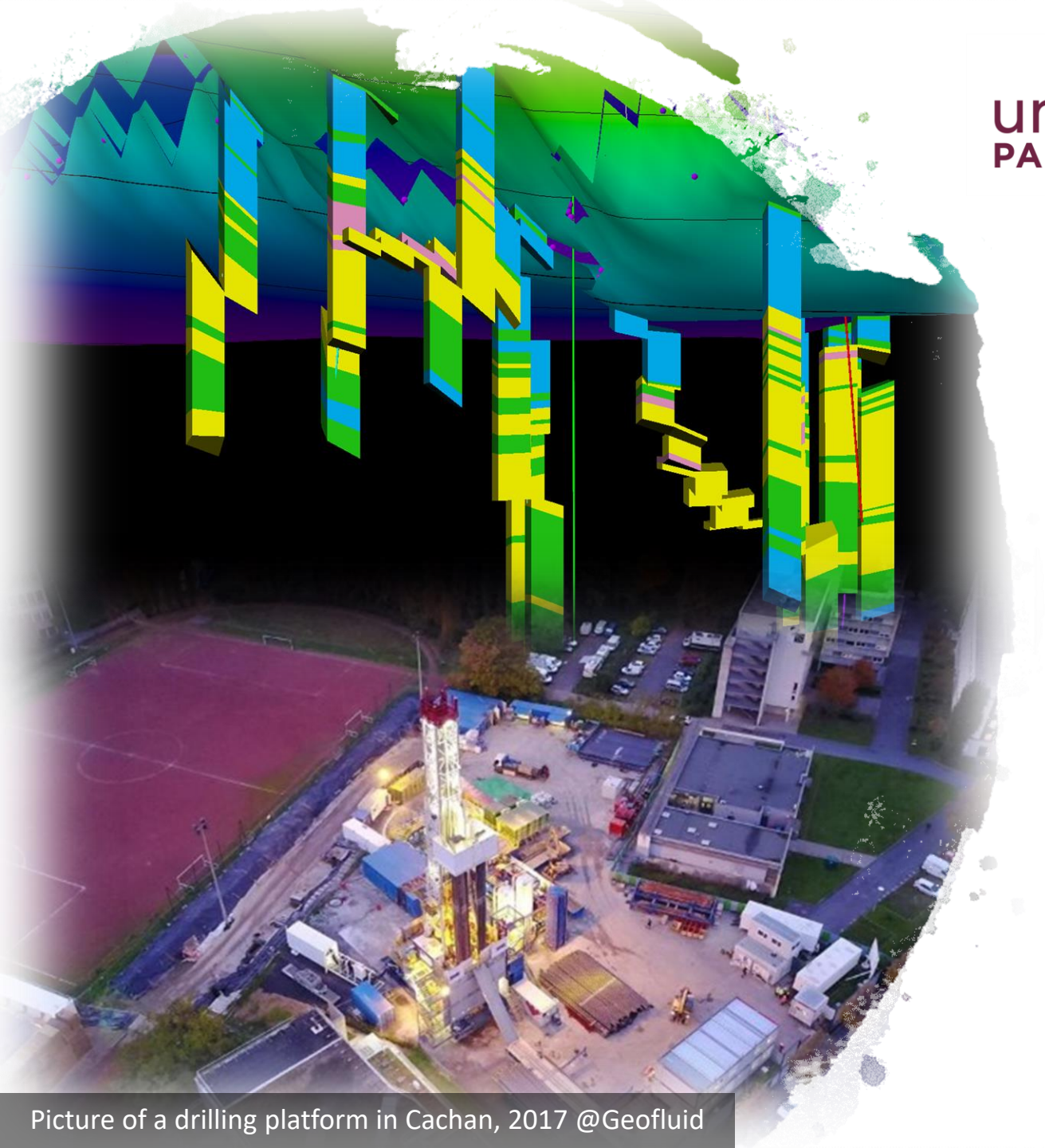

Picture of a drilling platform in Cachan, 2017 @Geofluid

Facies, porosity and permeability prediction and 3-D geological static model in the Middle Jurassic geothermal reservoir of the Paris Basin by integration of well logs and geostatistical modeling

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The Paris Basin, more specifically near Paris, in a very densely populated region with immense needs in energy. With the global warming problematic and the increasing needs in energy, renewable sources are starting to be considered and exploited. The geothermal energy is one of the exploited energies

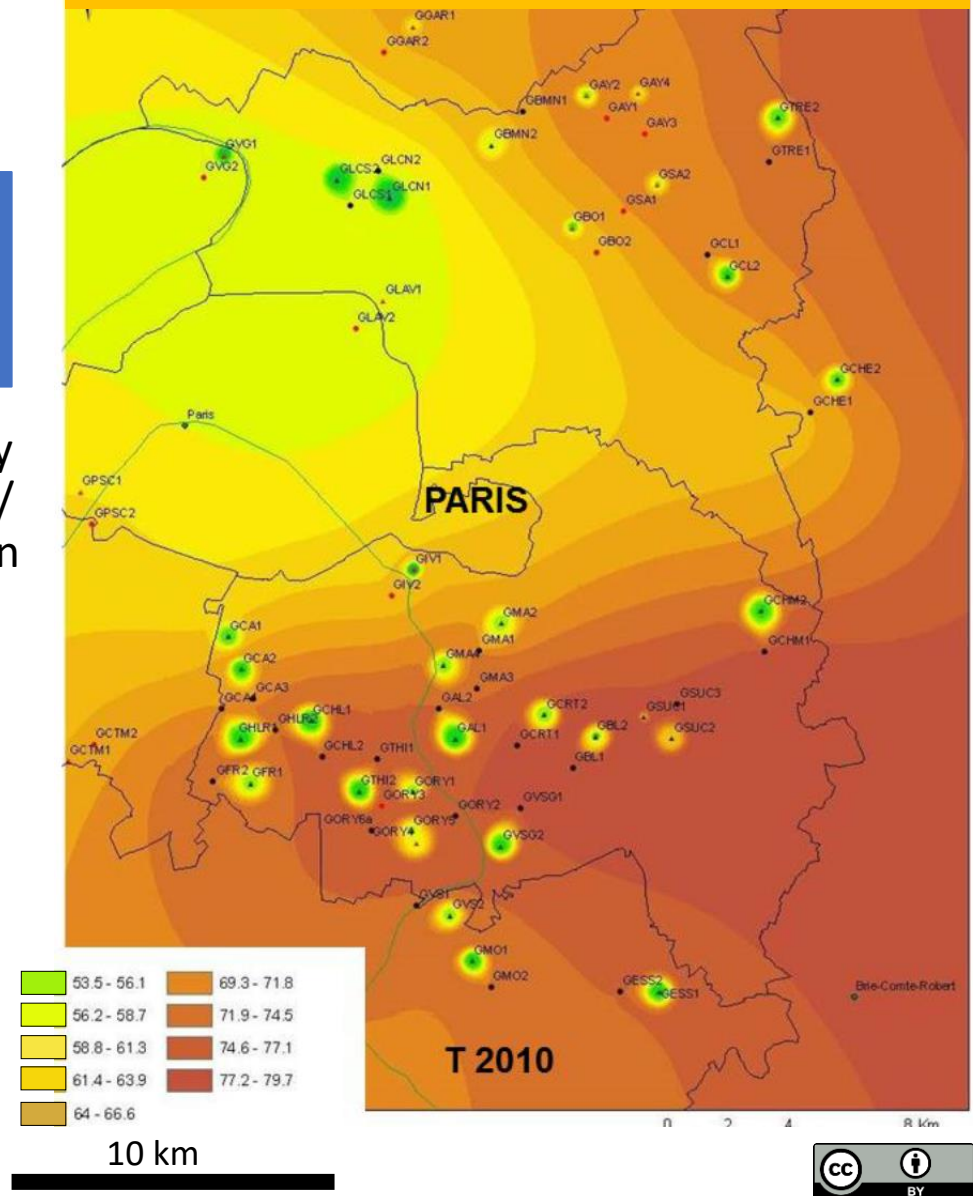
In the Ile-de-France region, the Energy-Climate plan has fixed as a guideline to produce 37 TWh of renewable energy in 2030, doubling the actual production of 18 TWh, with 3 TWh produced by deep geothermal exploration. The objective for the geothermal branch is to reach 6,4 TWh by 2023. The current rate of expansion will not allow to accomplish the initial objective.

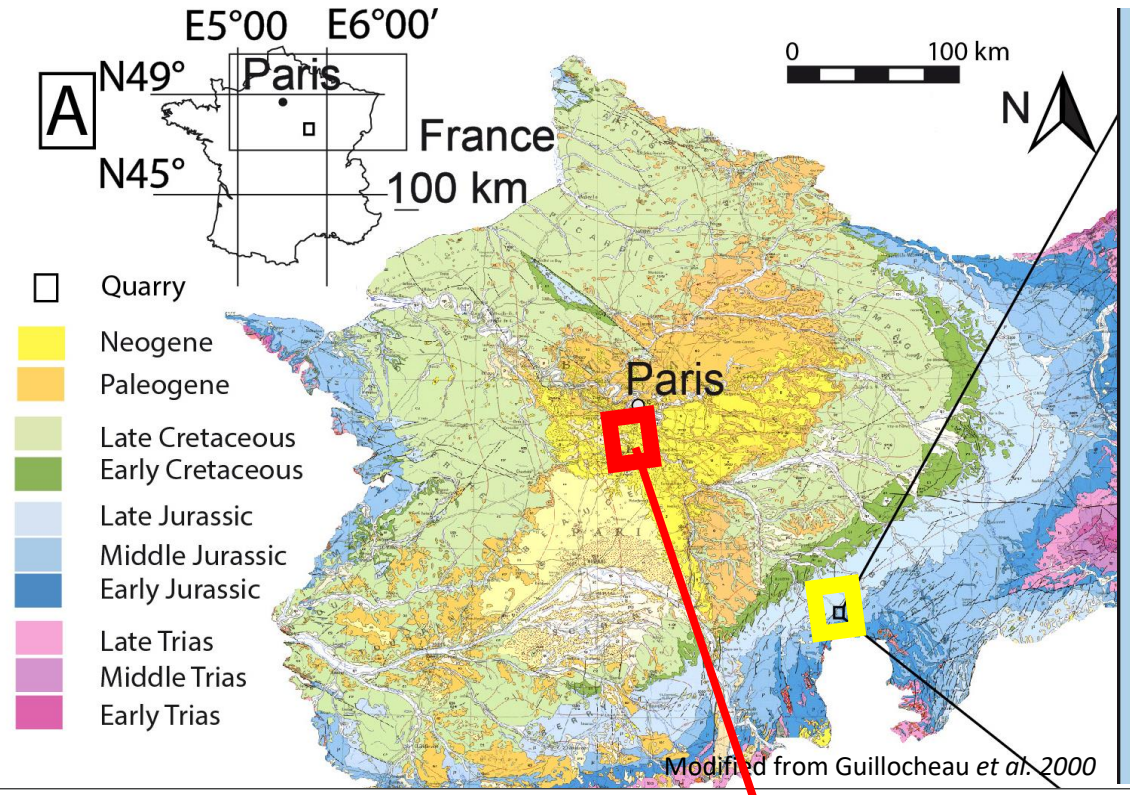
- Geological risk is an obstacle to the future development of geothermal energy in France and the Ile-de-France region. Problems such as low water flow rate / low reservoir thickness (metric), interference between geothermal doublets in urban areas with high infrastructure density or the risk of early thermal breakthrough are not very well characterized and make geothermal investments riskier.
- The objectives of this study are

(1) Provide a robust geological model of the reservoir heterogeneity (facies, porosity and permeability)

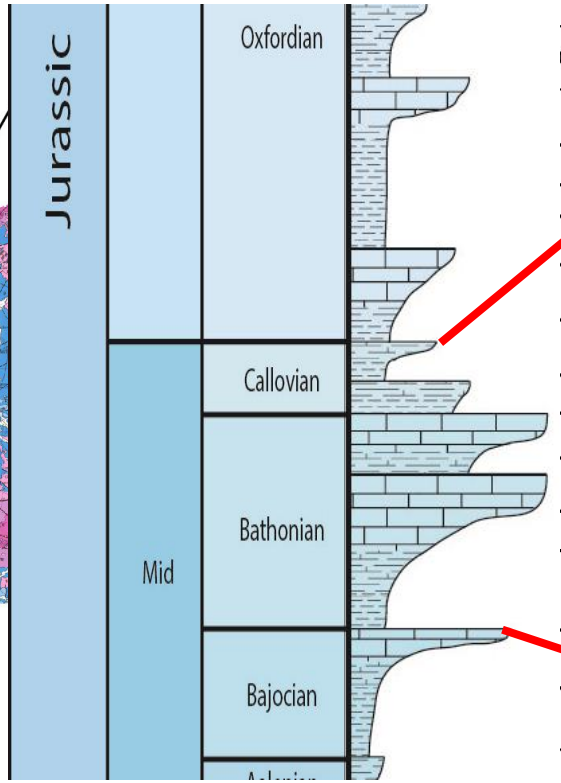
(2) Reconstruct a 3D reservoir analogue from outcrop (Massangis quarry in Burgundy, Paris Basin)

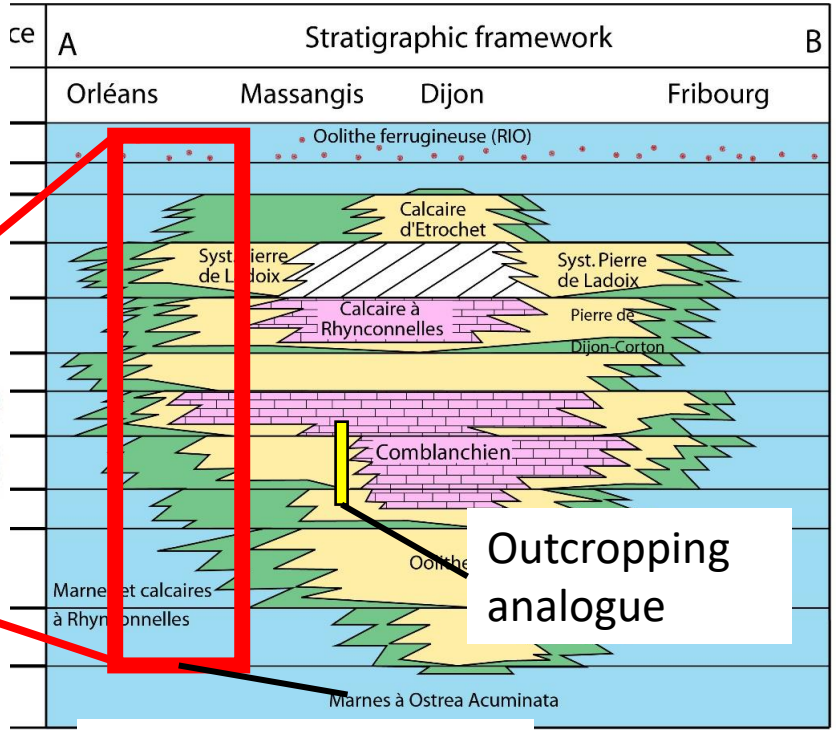
Exemple of temperature evolution of the Middle Jurassic – https://www.brgm.fr/projet/gestion-ressource-geothermique-dogger-ile-france BRGM (from S. Lopez *et al.*, 2010)





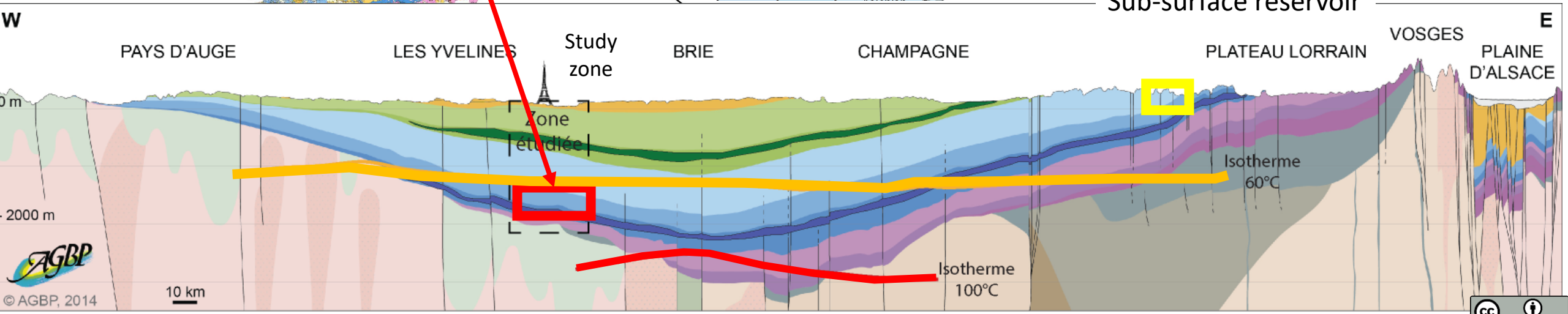
Modified from Guillocheau *et al.* 2000



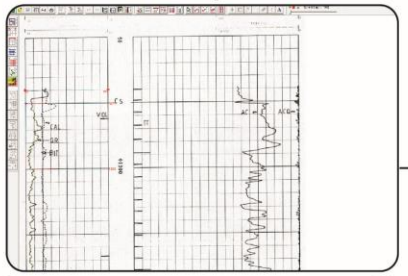


Outcropping analogue

Sub-surface reservoir



Data acquisition

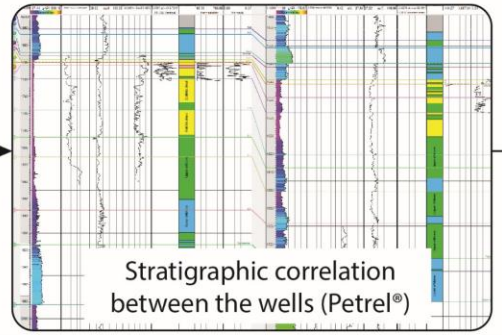


Digitization of scanned data from old wells
Extraction of petrophysical data from the

Field work:
- sampling
- logging
- facies description

Stratigraphical, structural and facies model

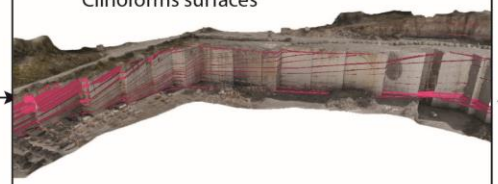
- 68 wells at the top of the Lower Callovien / Upper Jurassic
- Diagraphic data: 330 logs imported on the model
- 804 porosity/permeability plugs
- 156 thin sections in the mid Jurassic
- Description of 110 m of cores
- Faults / structural model



Stratigraphic correlation between the wells (Petrel®)

Image processing / digital outcrop model / interpretation

Photogrammetry modeling (Pix4D®)



Photogrammetric model interpretation (VRGS®)

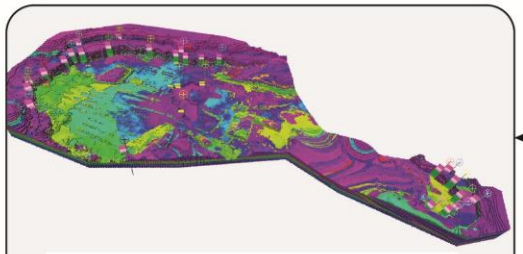
Properties data from the bibliography

- Total porosity (ϕ)
- Micro porosity (mϕ)
- Permeability (k)

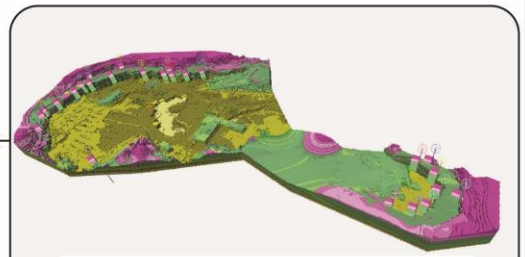
Petrophysical data of this study

- Macro porosity (Mϕ)

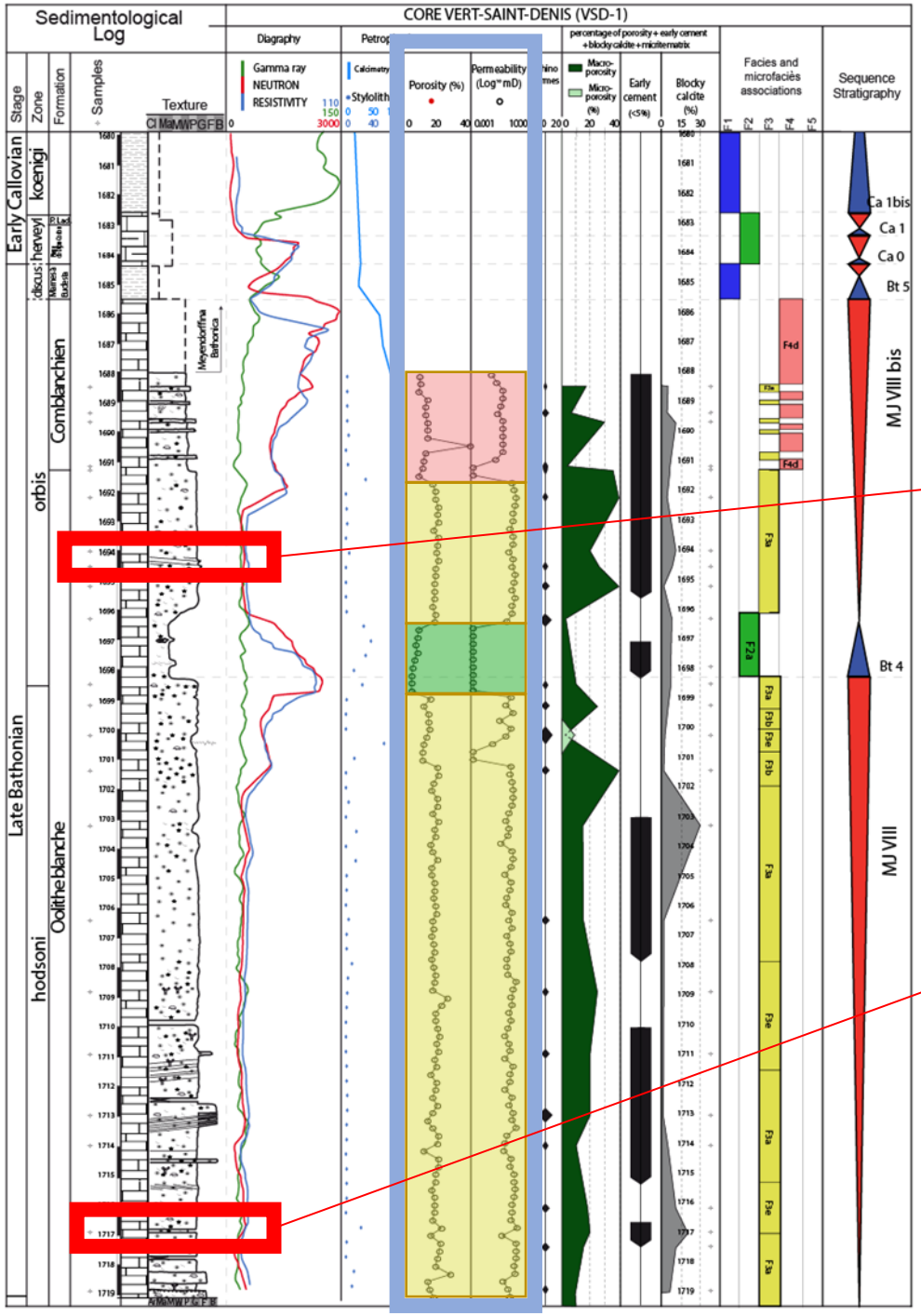
Model building (Petrel®)

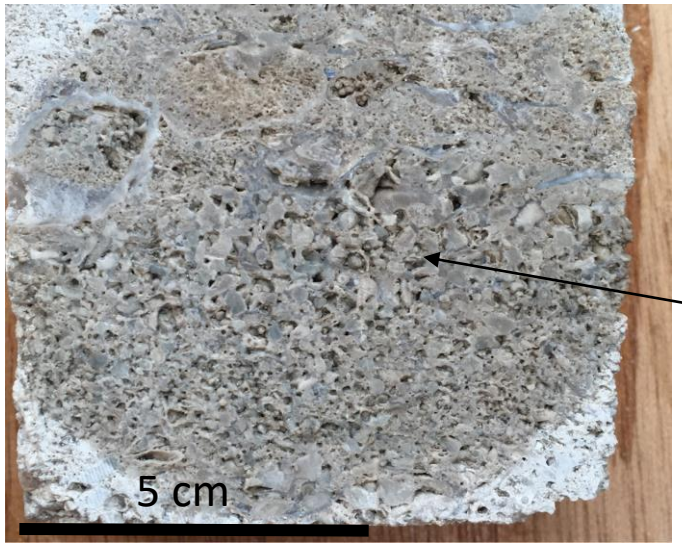


Porosity
Permeability



Key surfaces and facies architecture modeling

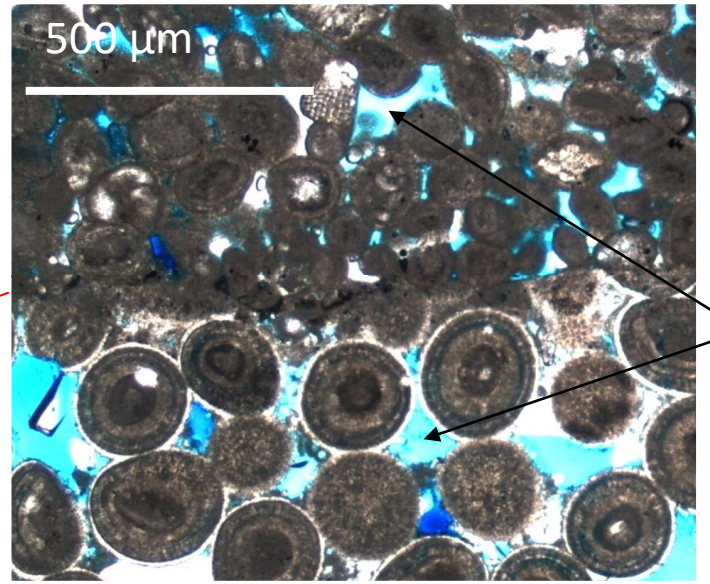




Sub-surface model
Middle Jurassic reservoir
Vers-Saint-Denis, 1694 m

Porosity visible to the naked eye

Porosity: 19,5%
Permeability: 241 mD

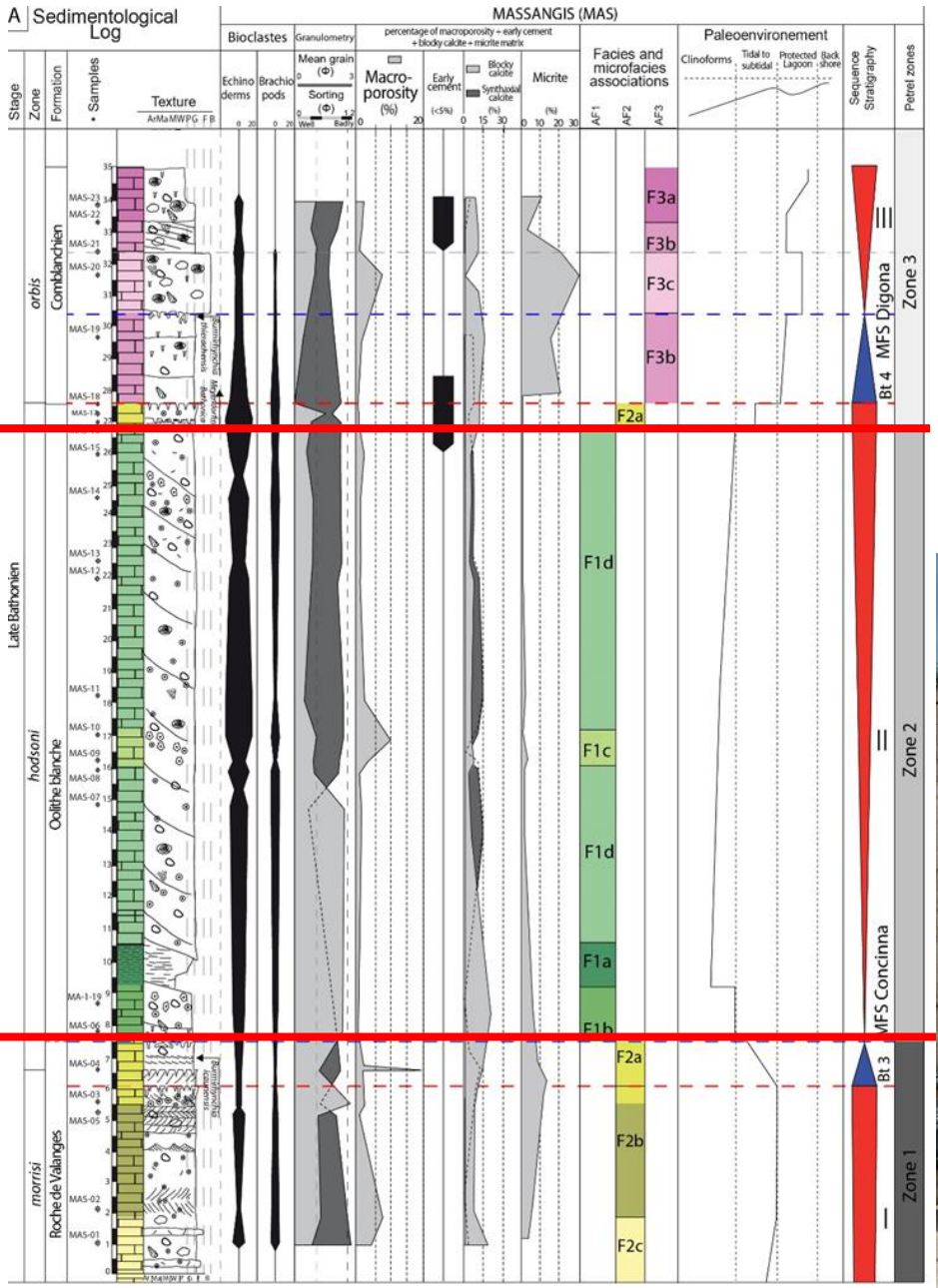


VSD-1-1716,9 m

Porosity

Porosity: 21%
Permeability: 650 mD

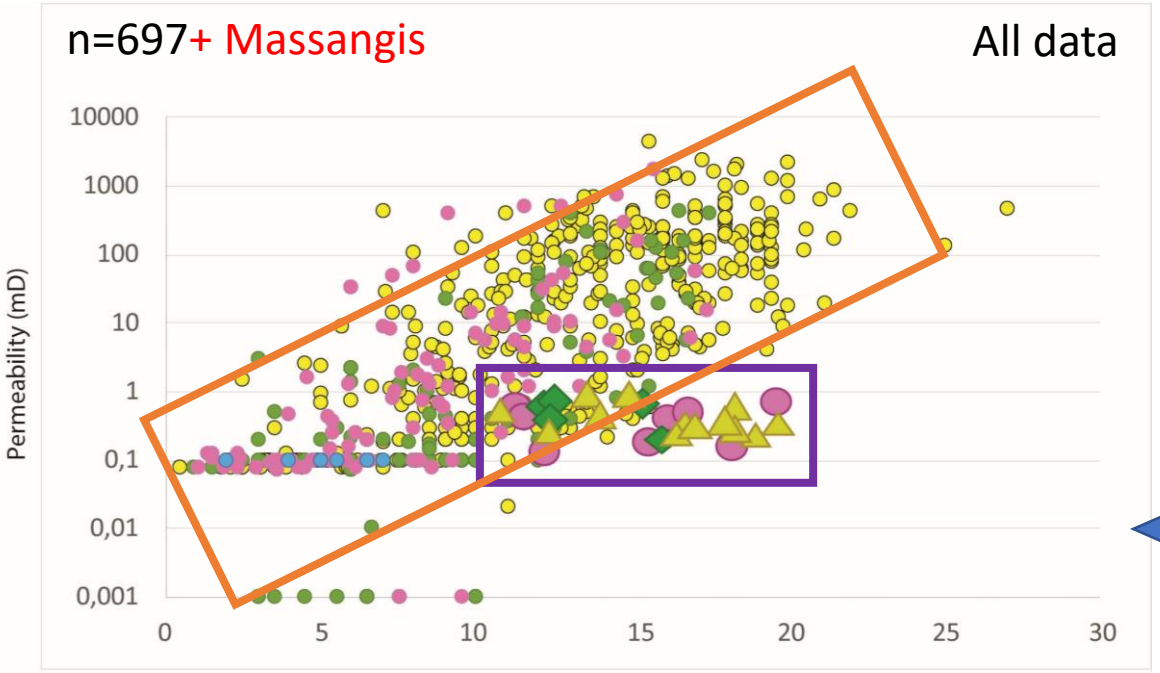
The core shows good reservoir properties, which is consistent with the observations already made. But some portions of the core indicate bad characteristics.



Reservoir analogue (Massangis, Burgundy)

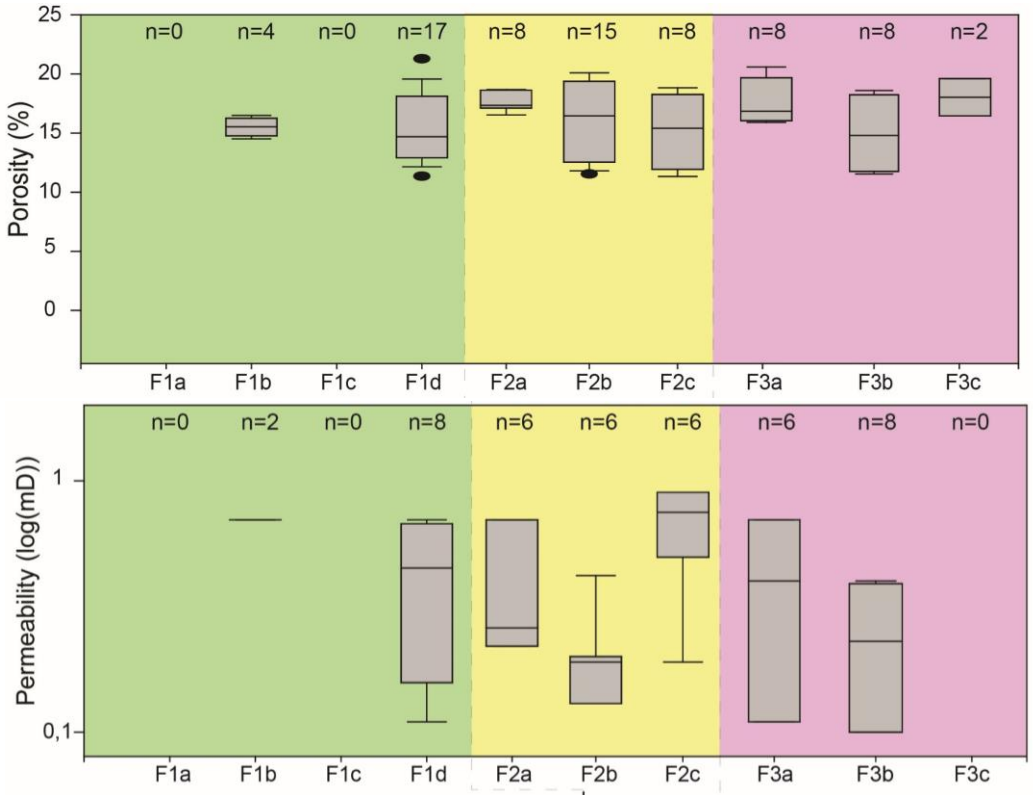
Clinoforms

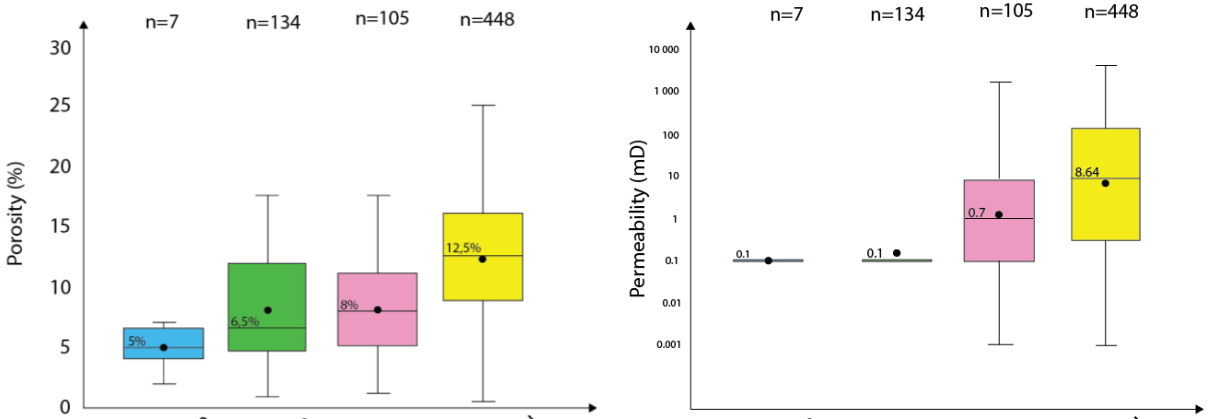
Petrophysical properties

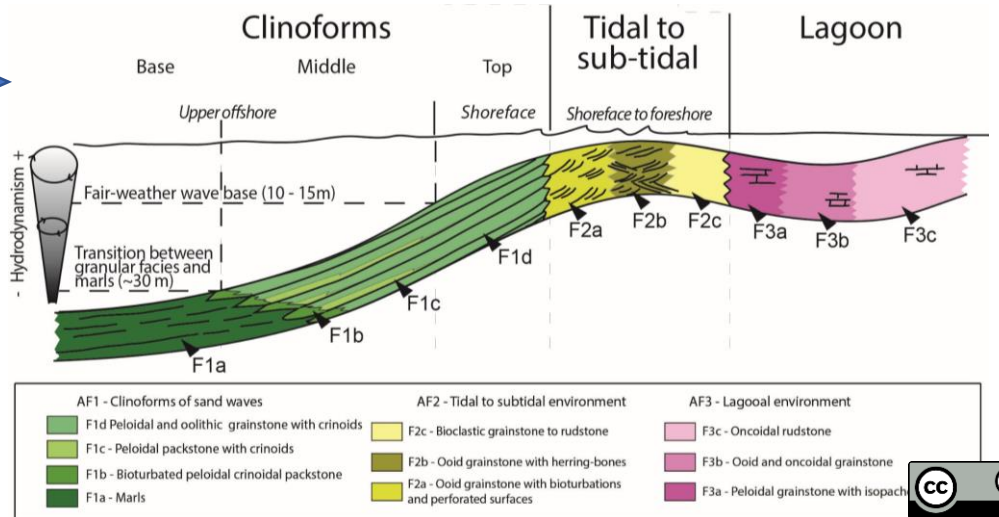


Sub-surface geothermal reservoir

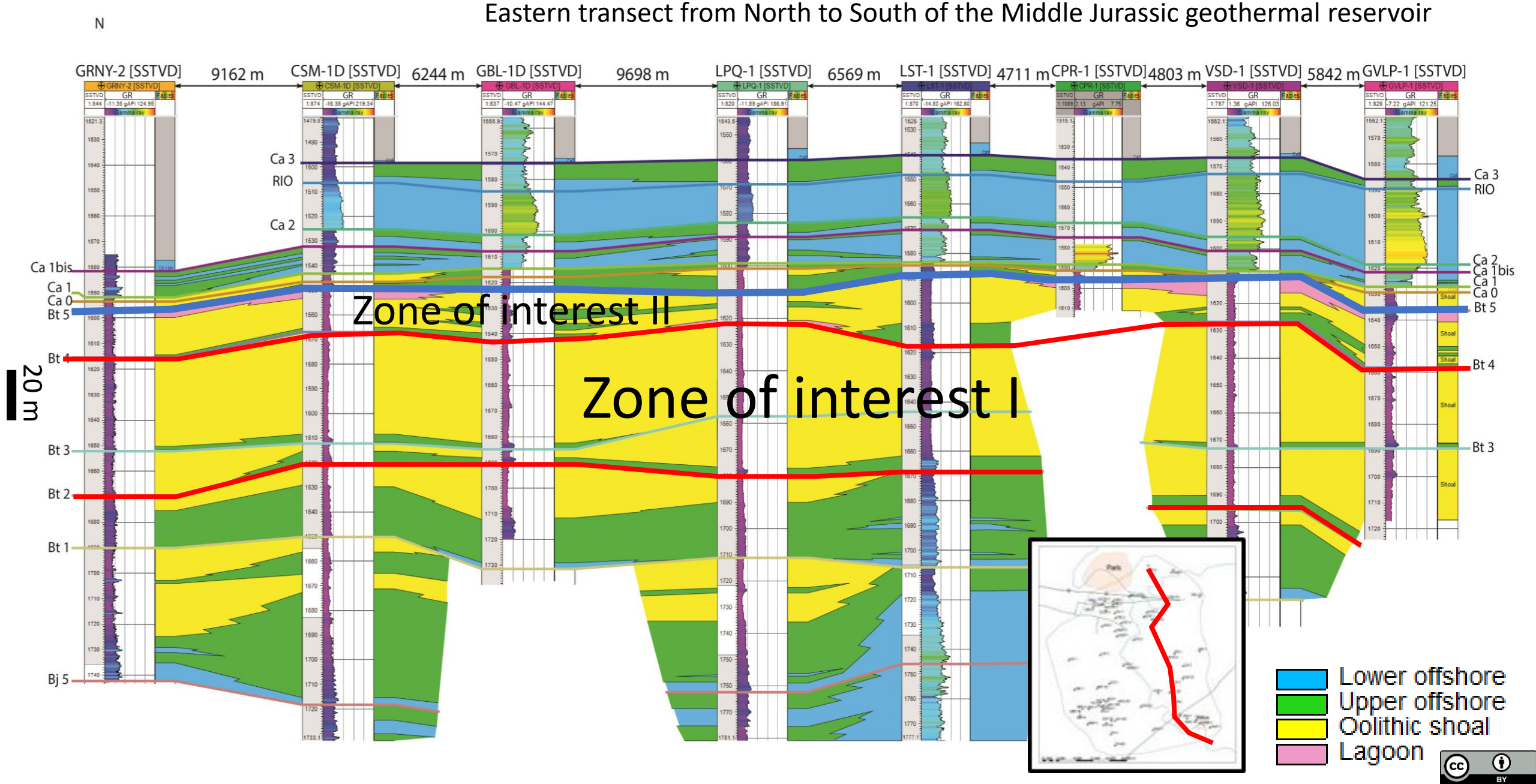
Quarry analogue

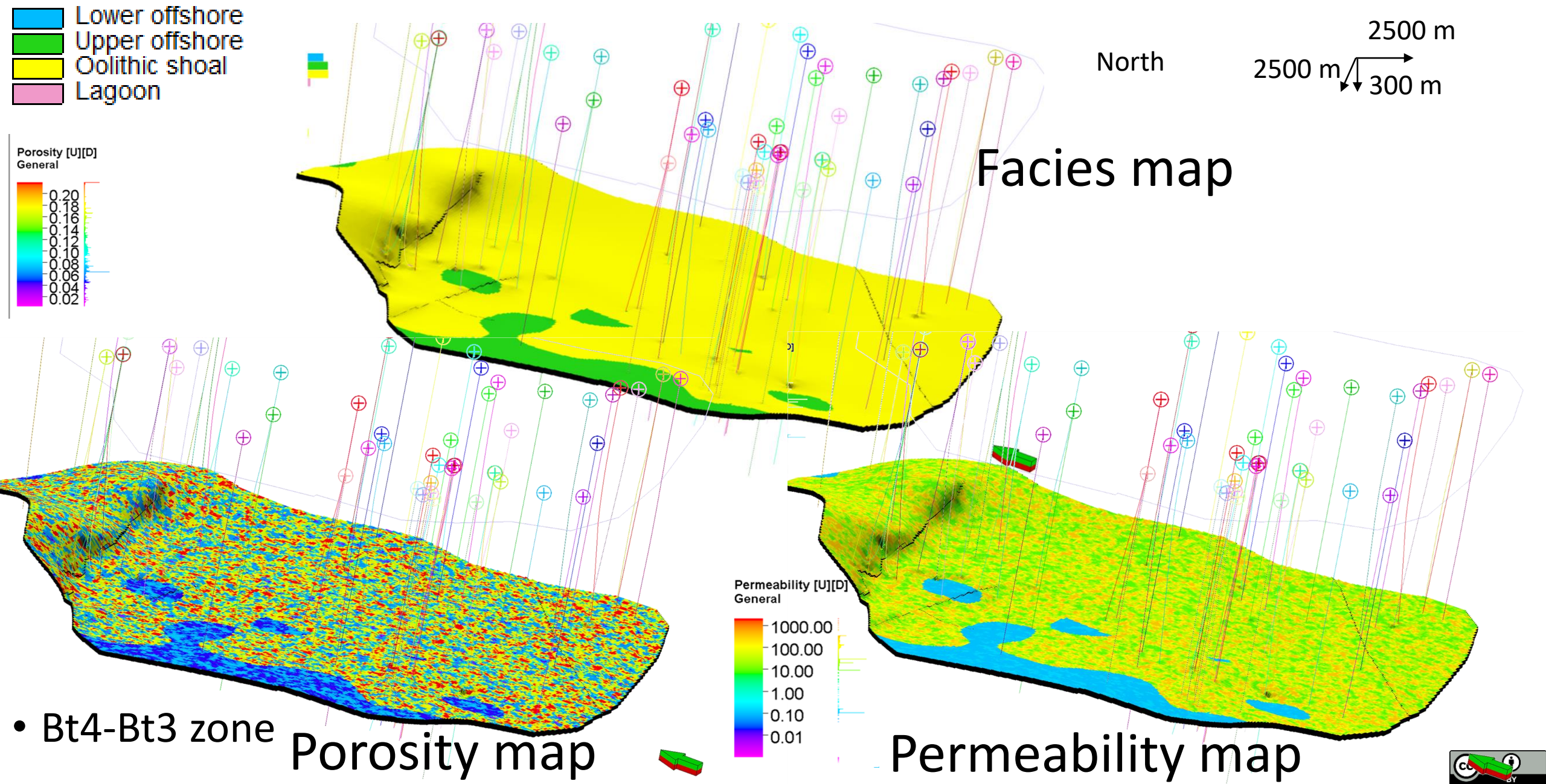






Eastern transect from North to South of the Middle Jurassic geothermal reservoir



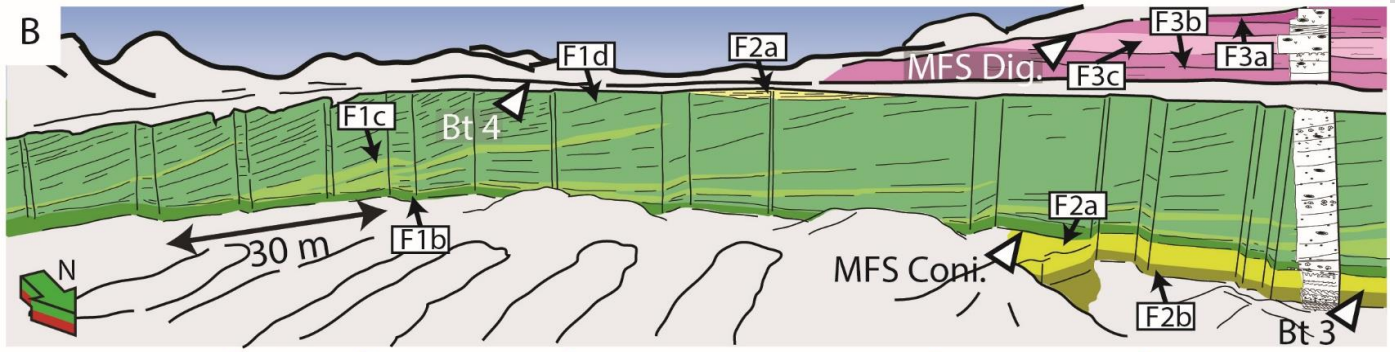


- Bt4-Bt3 zone

Porosity map

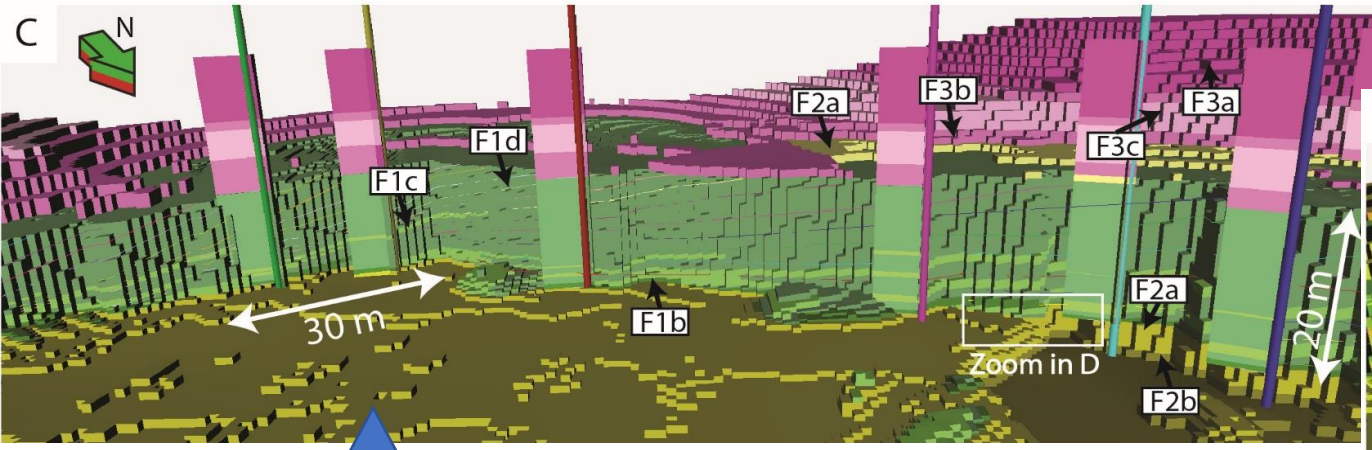
Permeability map

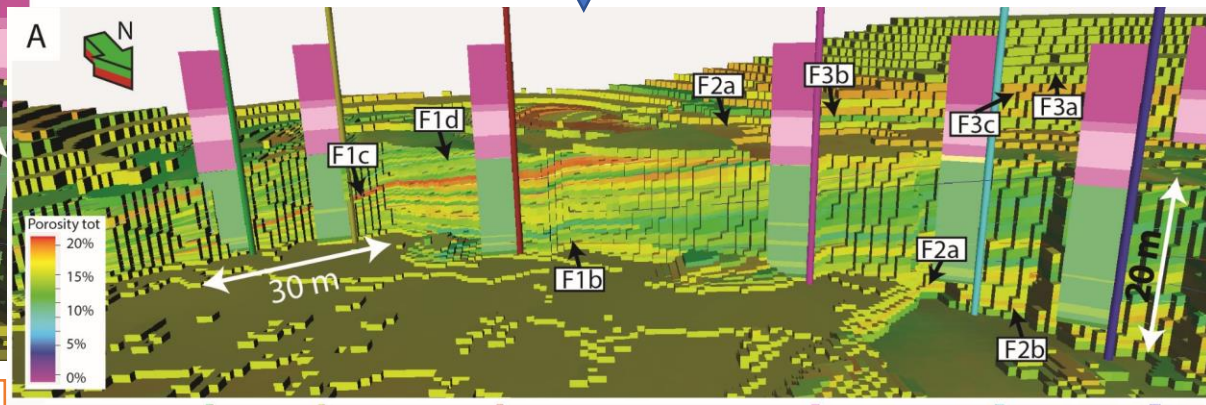
High resolution Reservoir-analogue model from Massangis outcrop



Observed facies on the photogrammetric model

Total porosity model
created using the facies bias and
performing a statistical data analysis



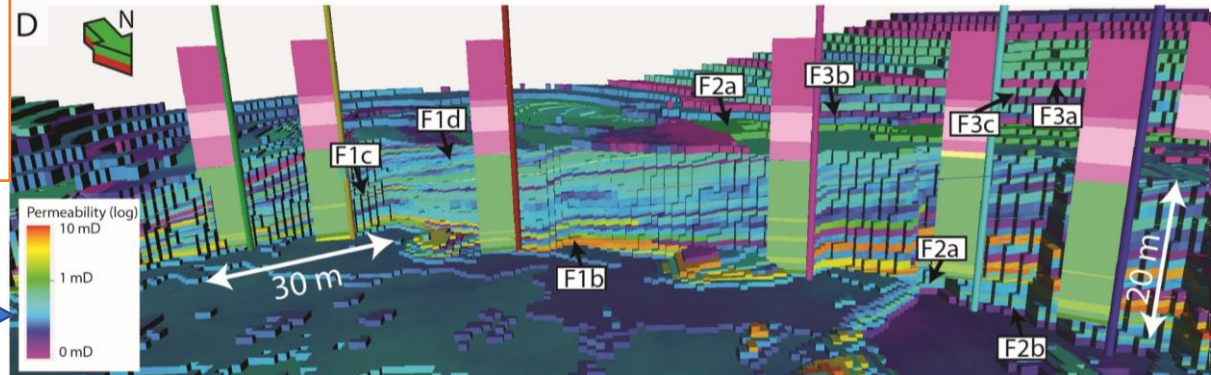


Deterministic facies model
Algorithm: « Truncated Gaussian with Trends »

- Bt4-Bt3 zone

Stratigraphic analogue of the sub-surface reservoir of the Paris Basin

60 millions of cells, 1m x 1 m x 0.9 m (XYZ)



Permeability model
Co-kriged to the porosity

- Conclusion:

Subsurface reservoir modelling:

- 11 3rd-order sequences, phi: 0-28 %, k: 0,01mD- >1 D
- 4 facies associations: upper offshore, lower offshore, shoreface and lagoon
- Good reservoir qualities are observed in shoreface and lagoonal facies associations
- Reservoir units are observed between sequence boundaries Bt2 and Bt4, well developed west of Paris (60-70 m of thickness)
- Petrographical observations in 3 wells indicate that reservoir porosity is mainly composed of intergranular pores.
- Temperatures of the aquifer averaging 70°C.

Massangis outcropping reservoir analogue:

- Combined use of drone-based photogrammetry (Pix4D®), VRGS® and Petrel® allows to constrain very precisely the facies architecture and heterogeneities along vertical and inaccessible outcrops, 60 millions of cells 1m x 1m x 0.9m (XYZ).
- Clinoforms correspond to sets of giant marine sandwaves of about 15-20 m height prograding N70° on the platform, allowing re-investigating subsurface reservoir geometries
- The relation between the different porosities and permeabilities indicates that the Massangis quarry model is a good analogue for microporous reservoirs with secondary porosity associated to dedolomitization.

Contribution of 3D outcrop modeling

- Reservoir units of the Middle Jurassic limestones of the Paris Basin (and other geothermal basins in the world) have similar mouldic rhombohedral pore spaces. The outcropping model serves as an analogue of many geothermal carbonate reservoirs dominated by rhomb-moulds.