Hydrogeological processes of karst-influenced multi-layered aquifers of northern Aquitaine basin, France

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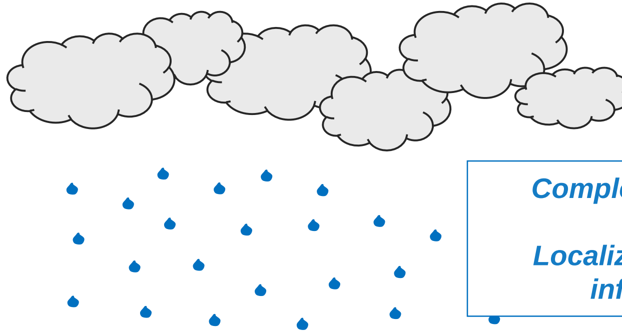
Introduction

Cabaret et al., 2017; Husson et al., 2016; Lorette, 2019; Platel et al., 2010; Von Stempel, 1972, etc.

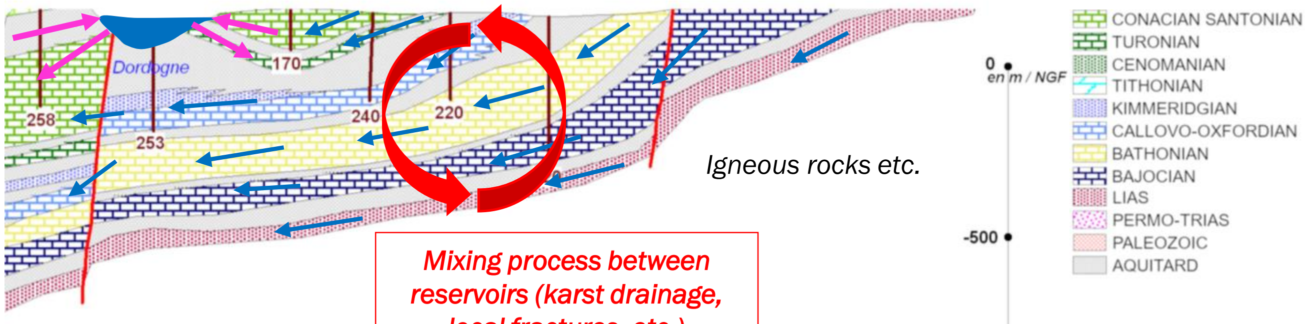
Eaux-SCARS



Complex recharge:

Localized + diffuse infiltration

Interaction with surface water



Mixing process between reservoirs (karst drainage, local fractures, etc.)

Sedimentary basin

Multilayer reservoir feature + Karst feature

➔ *Very complex and heterogeneous system*

Objective 1: characterize the regional hydrodynamic and hydro chemical variability of multi-layer carbonate aquifers located in the basin edge by considering their karst feature.

Objectifs

1. Détermination de la variabilité physico-chimique et hydrodynamique à large échelle

2. Comprendre les modalités de recharge et d’écoulement dans les systèmes carbonatés par une approche géochimique multi-traceurs

3. Développer une méthodologie pour caractériser le fonctionnement hydrogéologique et hydrogéochimique (captivité ou de non confinement, des mélanges entre aquifères, de l’évolution spatiale et temporelle)

4. Identifier les principales sources des pollution azotés et comprendre ses modalités de transfert (surface et souterraine)

→

Analyses statistiques et spatialisation de la donnée

Méthodologie isotopique

Méthodologie hydrochimique

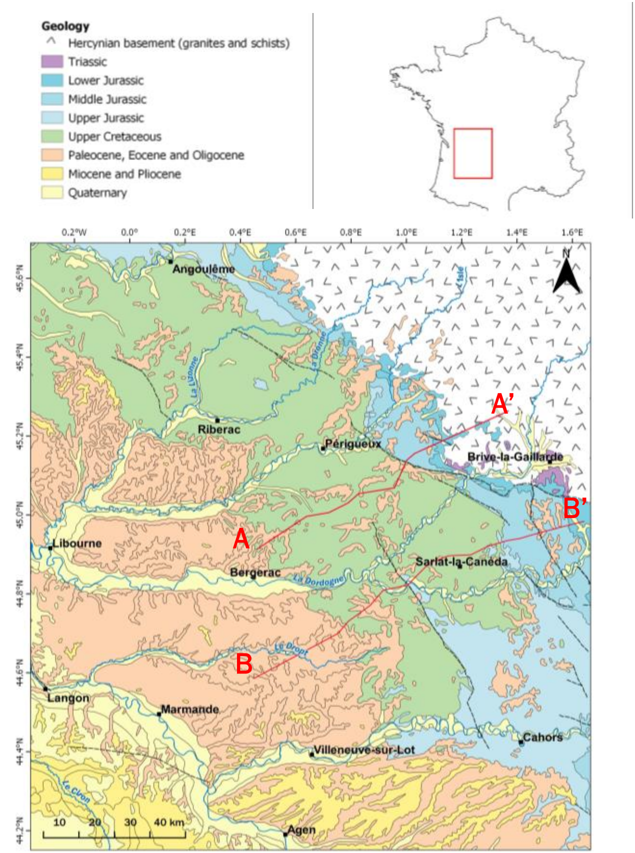
Modélisation hydrochimique (Phreeqc)

Study Area

Northern Aquitaine Basin (AB) in Southwest France.

Sediments from Triassic to Upper cretaceous overly the Hercynian granite and schist basement

The alternation of aquifers and aquitards create a complex multilayer aquifer system, characterized by 2 main reservoirs:

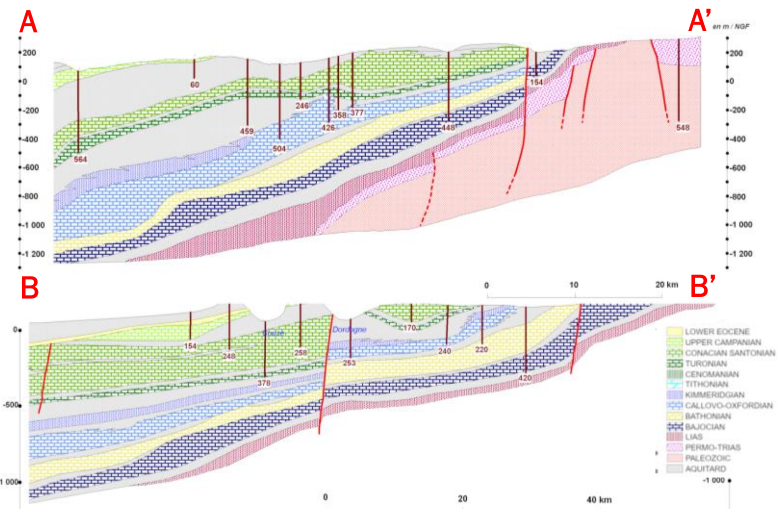


Study area in the edge North Aquitaine Basin (southwest France)

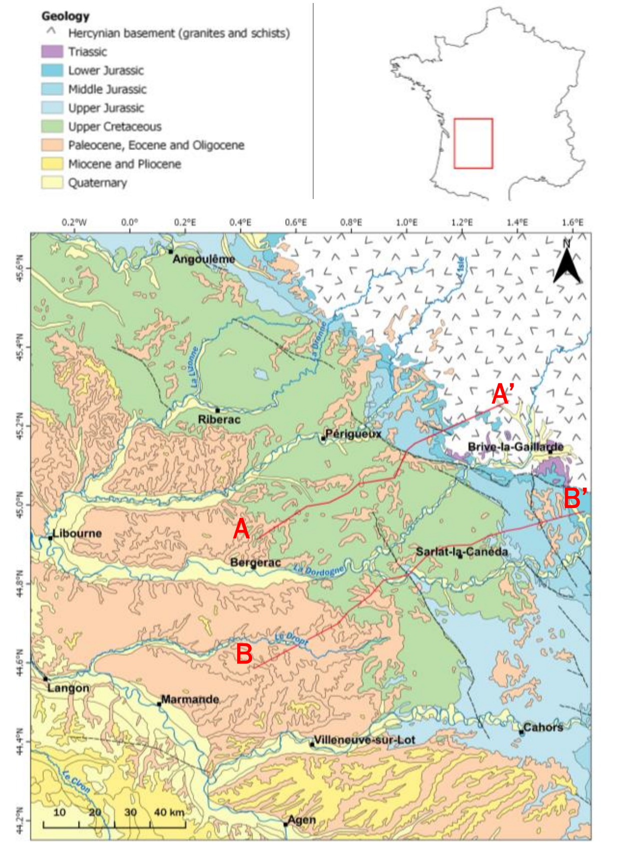
Study Area

Upper cretaceous multi-layer system, mainly composed of fractured limestone and contains four aquifers: Cenomanian, Turonian, Coniacian-Santonian and Campanian.

Jurassic multi layer system, mostly dolomitized, and composed by 5 reservoirs: Lias, Bajocian, Bathonian - Callovian – Oxfordian (the thickest and the most important), Kimmeridgian and the local reservoir of Tithonian.



Hydrogeological cross sections (adapted from Platel et al., 2010).



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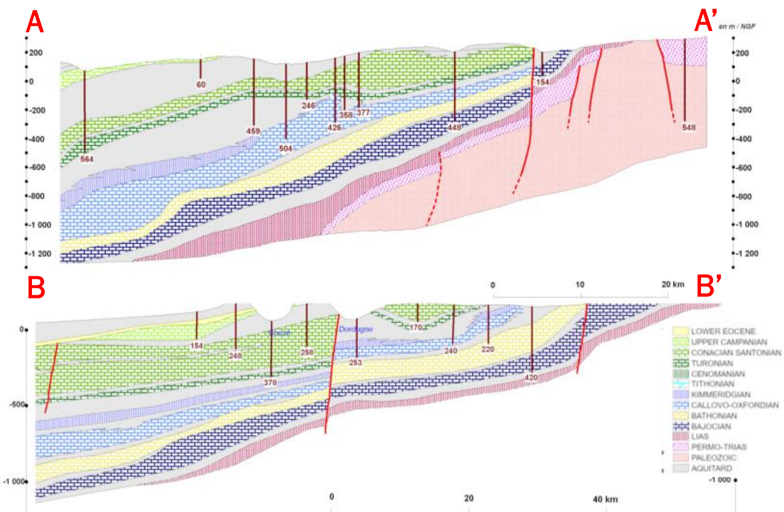


Hydrogeological cross sections (adapted from Platel et al., 2010).

*These predominantly carbonate formations are **<u>karstified</u>**, both **<u>outcrop and undercover</u>***

PART 1: Hydrochemical and hydrodynamic variability

Materials and methods

Groundwater and hydrological dataset was compiled from several public data-bases:

1. Hydrochemical data (major elements) and water levels
2. Geological and technical information from springs and wells

La Banque du Sous-Sol (BSS)

1. Piezometric maps

- 29 in Upper Cretaceous aquifers (Turonian and/or Coniacian Santonian and/or Cenomanian)
- 25 in Jurassic aquifers (Bajocian and/or Bathonian Callovian Oxfordian and/or Kimmeridgian)
- Dry and wet season 2017
- Standard Kriging interpolation

2. Hydrochemical maps and PCA

- 65 springs and shallow wells (max. 7 m depth), and 94 boreholes (up to 1.2 km in depth, 330 m in average)
- The boreholes screened both in the Jurassic and Upper Cretaceous aquifers were not selected
- A minimum of 5 samples per site over the 2000-2019
- Ionic balance greater than 5% was not accepted
- Temperature, pH, EC at 25 °C, and chemical analyses of major elements
- Use of the median value

3. Geothermal gradient

- Simple linear regression
- Calculated from 81 sites (boreholes) with a screen at least at 25 m deep.
- The screened interval must be less than 100 m

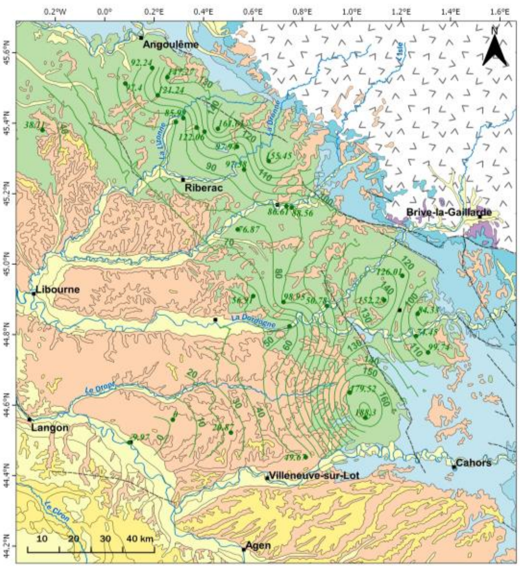
Results and discussion : Hydrogeological characteristics

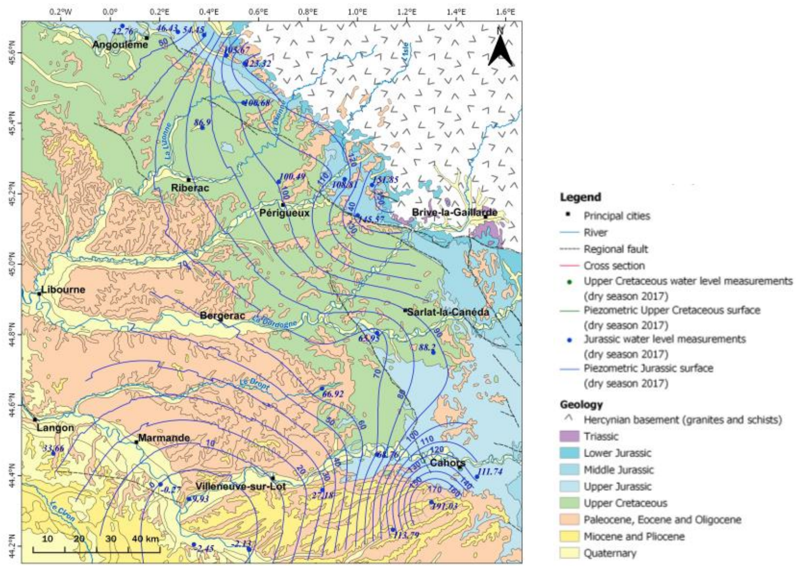
Upper cretaceous piezometric map dry season 2017

- Recharge zone on the Turonian and Conacian Santonian outcrops
- Rivers such as Dordogne, Lizonne, Dronne and Isle appear to drain the cretaceous aquifer.

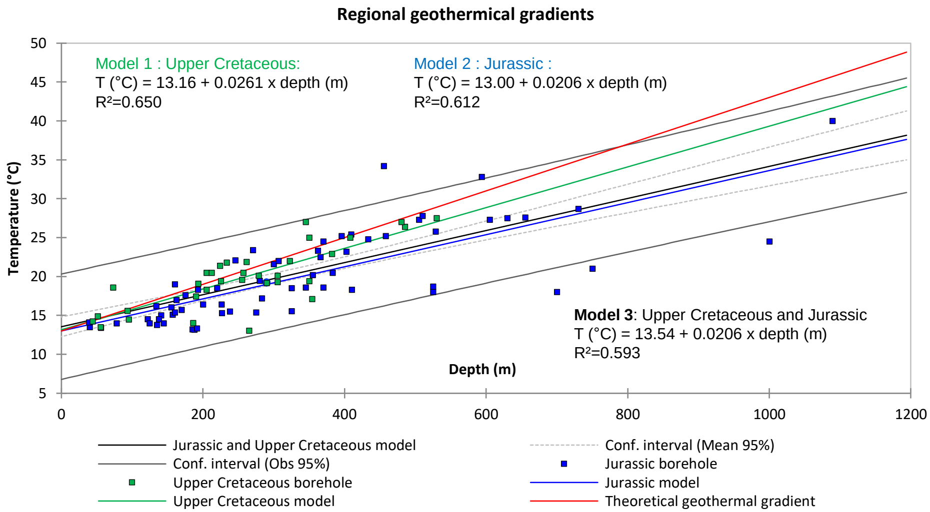
Jurassic piezometric map dry season 2017

- Two main flow direction are observed : EW (Perigueux area) and NE-SW between Sarlat-la-Canéda and Cahors
- Dividing line seems accentuated by the piezometric depression





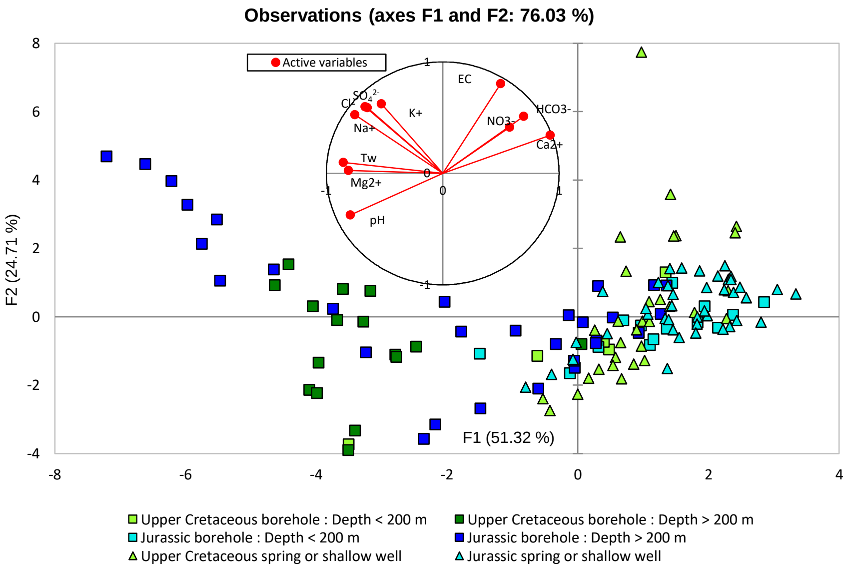
Results and discussion : Geothermal gradient



- Temperature variability in the Upper Cretaceous and Jurassic aquifers; 13.5 to 40 °C
- Global regional geothermal gradient of 2.060 °C/100 m

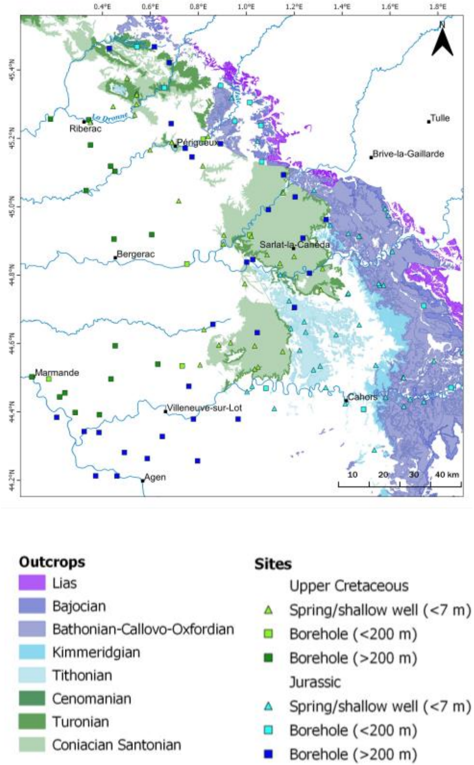
Cold-water anomalies at important depths

Results and discussion : Hydrochemical variability



Plot based on principal components analysis of hydrochemical sampling from springs and boreholes

Sites localization



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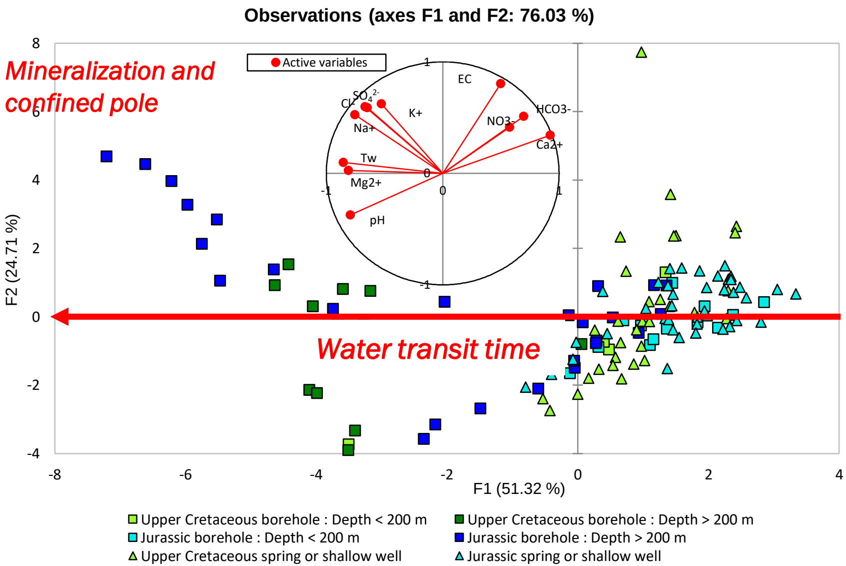

Plot based on principal components analysis of hydrochemical sampling from springs and boreholes

Variables: Mg^{2+} well correlated with Tw and negatively correlated with Ca^{2+} , HCO^{-} and NO_3^{-} .

Na^{+} , Cl^{-} , K^{+} and SO_4^{2-} are well correlated.

Observations:

1. Boreholes deeper than 200 m (with a few exceptions)
Strong concentrations of Mg^{2+} , Na^{+} , Cl^{-} and SO_4^{2-} ->mineralization

2. Springs, shallow wells and boreholes of shallow depth (<200 m) wigh high values of Ca^{2+} and bicarbonates

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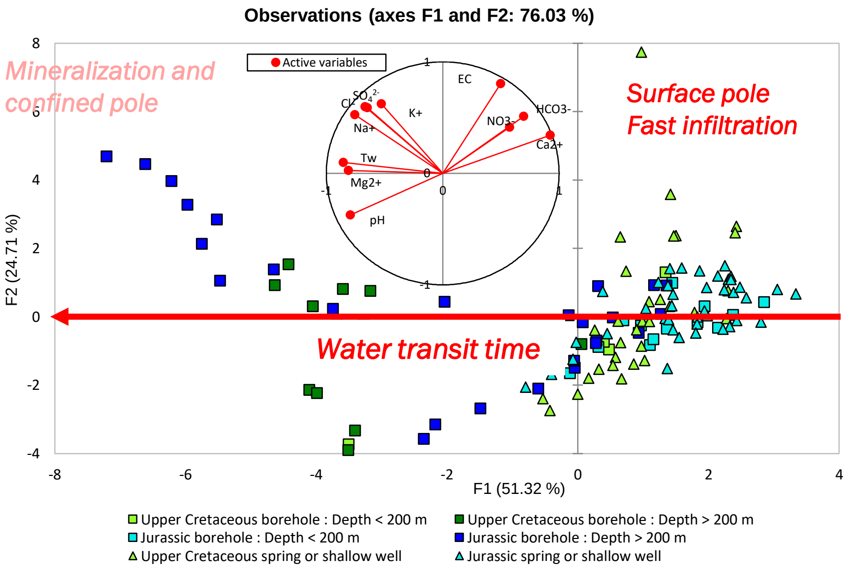

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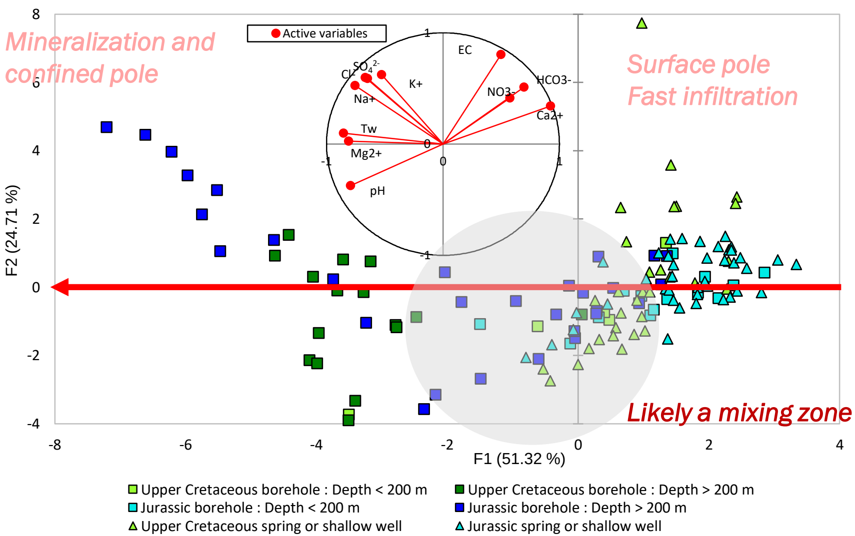

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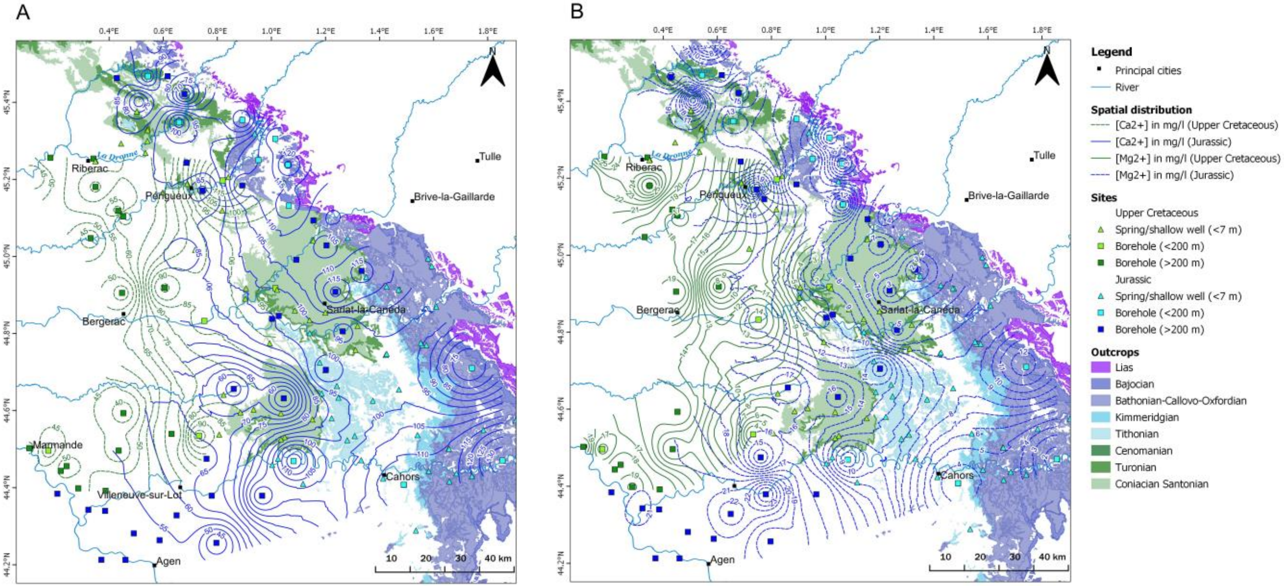
Results and discussion : Spatial variability

Spatial variability of Ca (a) and Mg (b) concentrations in both Upper Cretaceous and Jurassic aquifers.



- High concentrations of Ca2+ (around 120 mg/L)
- Ca2+ decrease from East to West and Southwest

- Low concentration of Mg2+ at the outcrops.
- Mg2+ increase from East to West and Southwest

PART 2: Approche isotopique

Materials and methods

Quatre campagnes de prelevement

	Campagne 01 BE Sept 2020	Campagne 02 HE Avril 2021	Campagne 03 BE Sept 2021	Campagne 04 HE Avril 2022	Campagne 05 BE Sept 2022
Eaux sout. (forages + sources)	43	43	43	43	43
Cours d'eau principaux	0	12	13	21	21
Cours d'eau secondaires	0	4	9	33	33
TOTAL	43	59	65	97	97

Analyses géochimiques et isotopiques :

- éléments majeurs
- Silice
- COD
- 18O/16O et 2H/1H (marqueur de l'origine de la recharge)
- 87Sr/86Sr (marqueurs de réservoir).

Analyses géochimiques et

PART 2: Approche isotopique

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$^{87}Sr/^{86}Sr$

+ [Sr]

- ^{87}Sr, isotope radiogénique
- Provient de la décroissance radioactive b^{-}, ou t ½ = 48.8 $*10^{9}$ ans)
- Le $^{87}Sr/^{86}Sr$ est considéré constant au long du cycle d’eau douce

La signature isotopique va dépendre principalement du lessivage des roches.

PART 2: Approche isotopique

Premières résultats:

$^{87}Sr/^{86}Sr$ + [Sr]

Au bordure de ***bassin sédimentaire aquitaine***:

1. Socle granitique du Massif Central:

C'est les plagioclases et biotites qui vont contrôler la signature isotopique (altération et moins solubilité relative)

➡ Concentrations faibles en strontium + Valeurs plus radiogéniques de $^{87}Sr/^{86}Sr$

2. Au sein des terrains carbonatés:

Le strontium est présent en traces dans des minéraux tels que la calcite, dolomite, gypse et anhydrite (le Sr2+ remplace au Ca2+ et Mg2+) - Solubilité relativement élevée

➡ Concentrations élevés de strontium et signature isotopiques moins radiogénique.

(Burke et al. 1982)

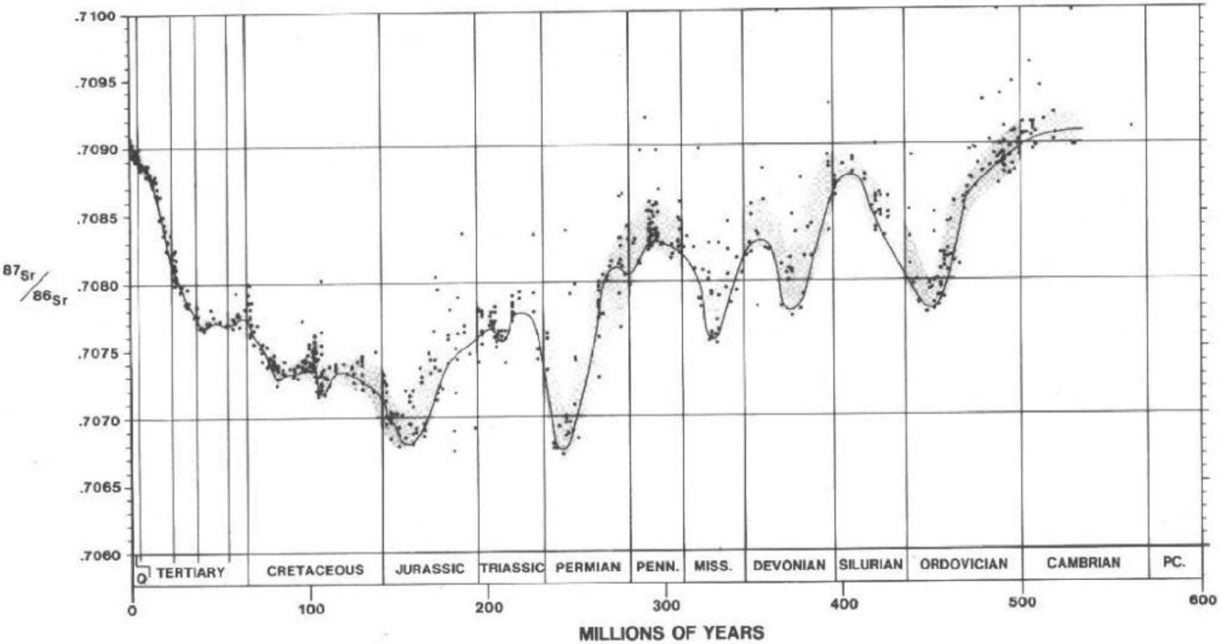
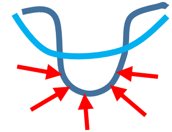


Figure 1. Plot of $^{87}Sr/^{86}Sr$ age for 744 of 786 marine samples. $^{87}Sr/^{86}Sr$ values for the 42 modern marine samples (Table 1) are not shown. Modern values, however, were accounted for in drawing band and line. For any given time, correct seawater ratio probably lies within band. Line represents our best estimate of seawater ratio versus time. Pre-Cenozoic ages are based on van Eysinga (1975). Cenozoic ages are based on time scale provided by L. B. Gibson (1980, personal commun.). Pliocene-Pleistocene boundary is at 1.62 m.y. B.P., and Tertiary stage boundaries are at 5.0, 23.5, 37.0, and 53.5 m.y. B.P.

PART 2: Approche isotopique

Premières résultats:

Possible configuration



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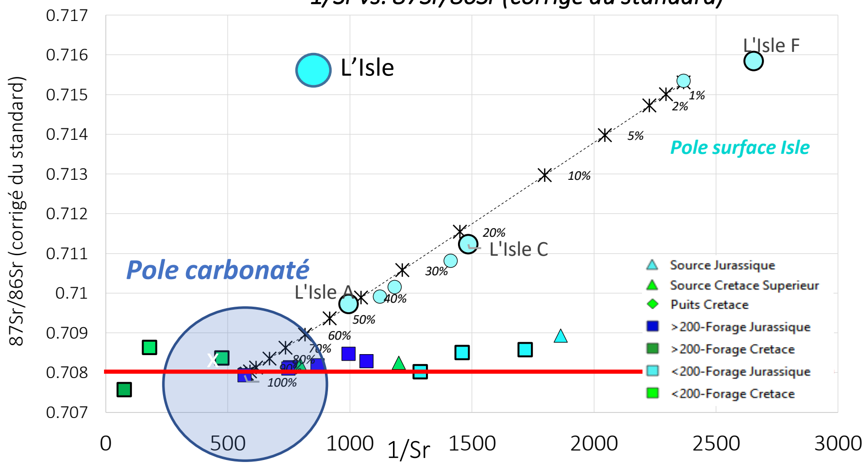
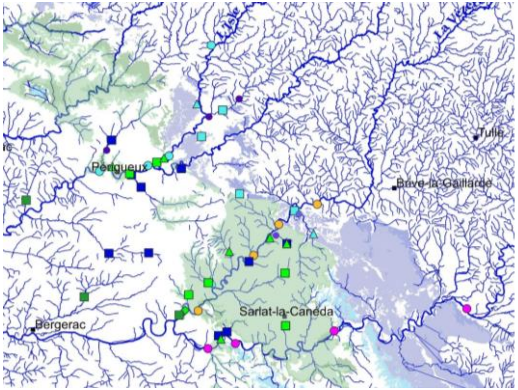
1/Sr vs. 87Sr/86Sr (corrigé du standard)





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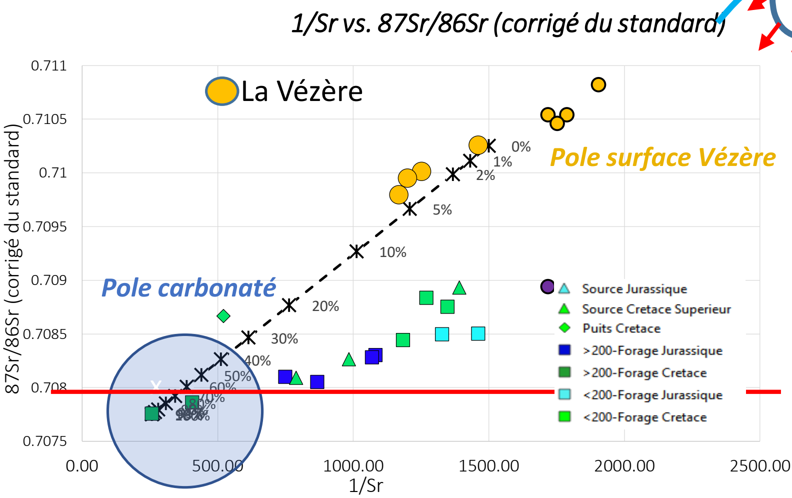

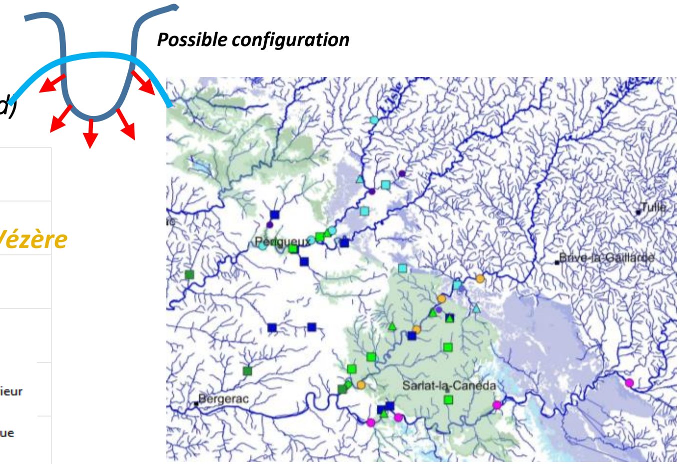

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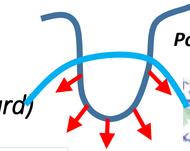

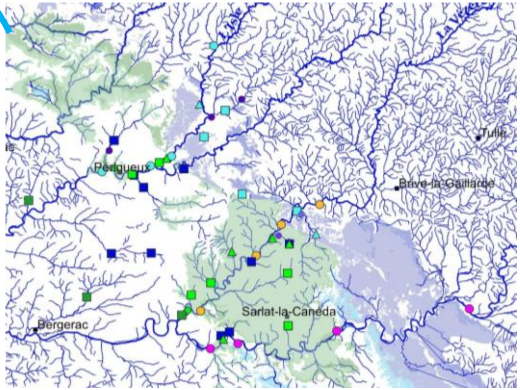

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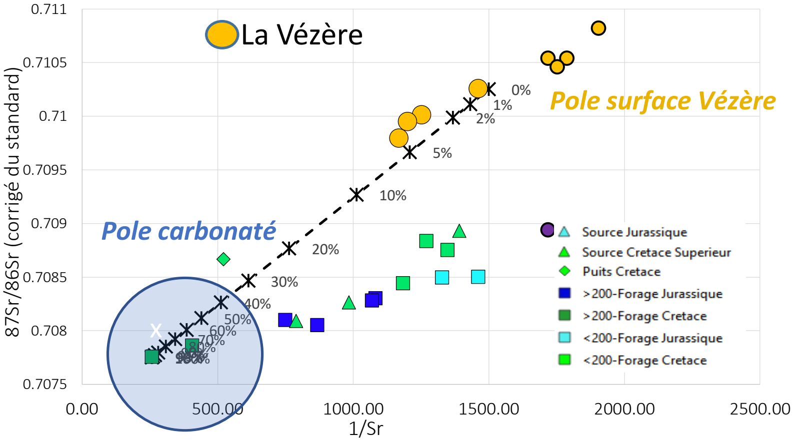

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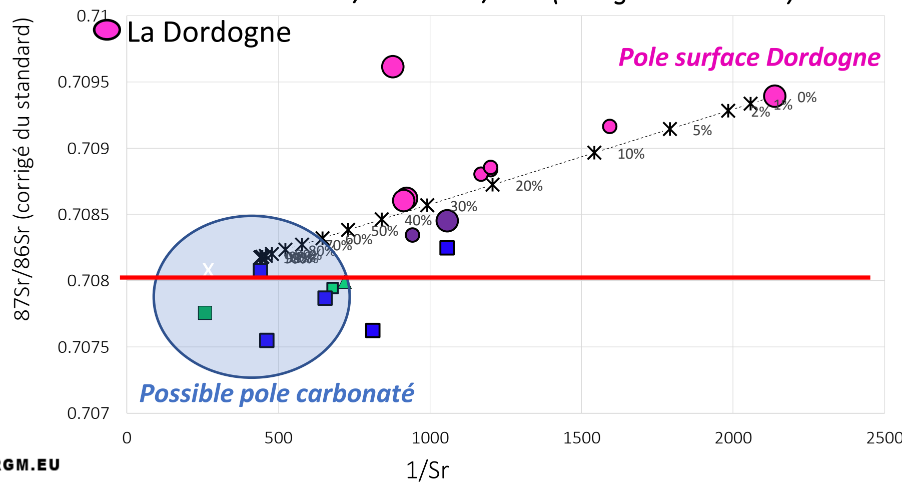

- *Sur la Dordogne, quel configuration?*
- *Chaque axe de rivière a un comportement différent.*
- *Rôle des petites affluents carbonatés -> résultats à recevoir.*

Conclusions:

- The Upper Cretaceous and Jurassic aquifers are widely heterogeneous.
- The hydrogeochemistry varies according the lithology facies, the residence time, the depth, and very likely because of the karstic feature.
- Our results show evidences of mixing zones between the two main Cretaceous and Jurassic reservoirs.
- This is probably due to the karstic and fractured natures of the carbonate formations that allow a fast infiltration through vertical drainage of water from the surface towards the deep parts of the aquifers
- The isotopic method ($^{87}Sr/^{86}Sr$) shows encouraging results to quantify the contribution of carbonate aquifers to the principal rivers.