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Salinization of coastal groundwaters in multi-layered sedimentary aquifers: multi-isotope constraints illustrated by examples in South of France and North East of Brazil

Petelet-Giraud E., Cary L., Négrel Ph., Bertrand G., Kloppmann W., Ladouche B.,Bailly-Conte V., Aquilina L., Hirata R., Montenegro S. and Dörfliger N.

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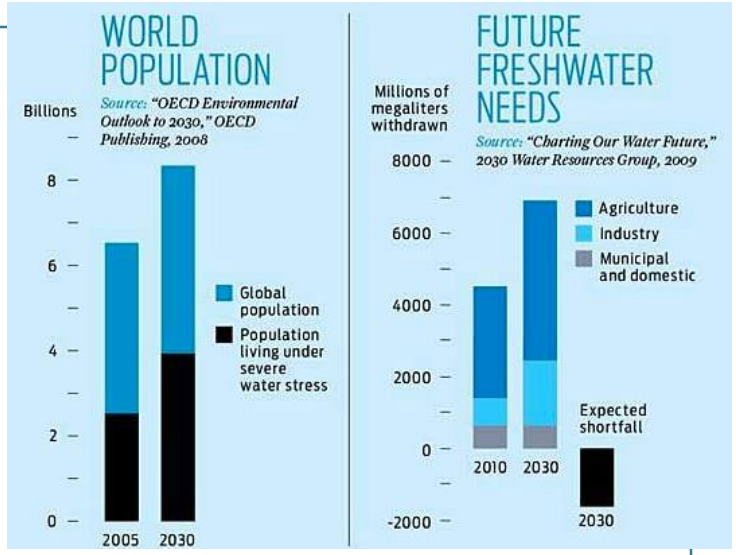
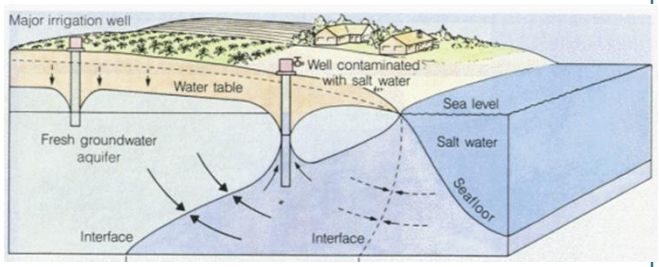
Coastal groundwaters

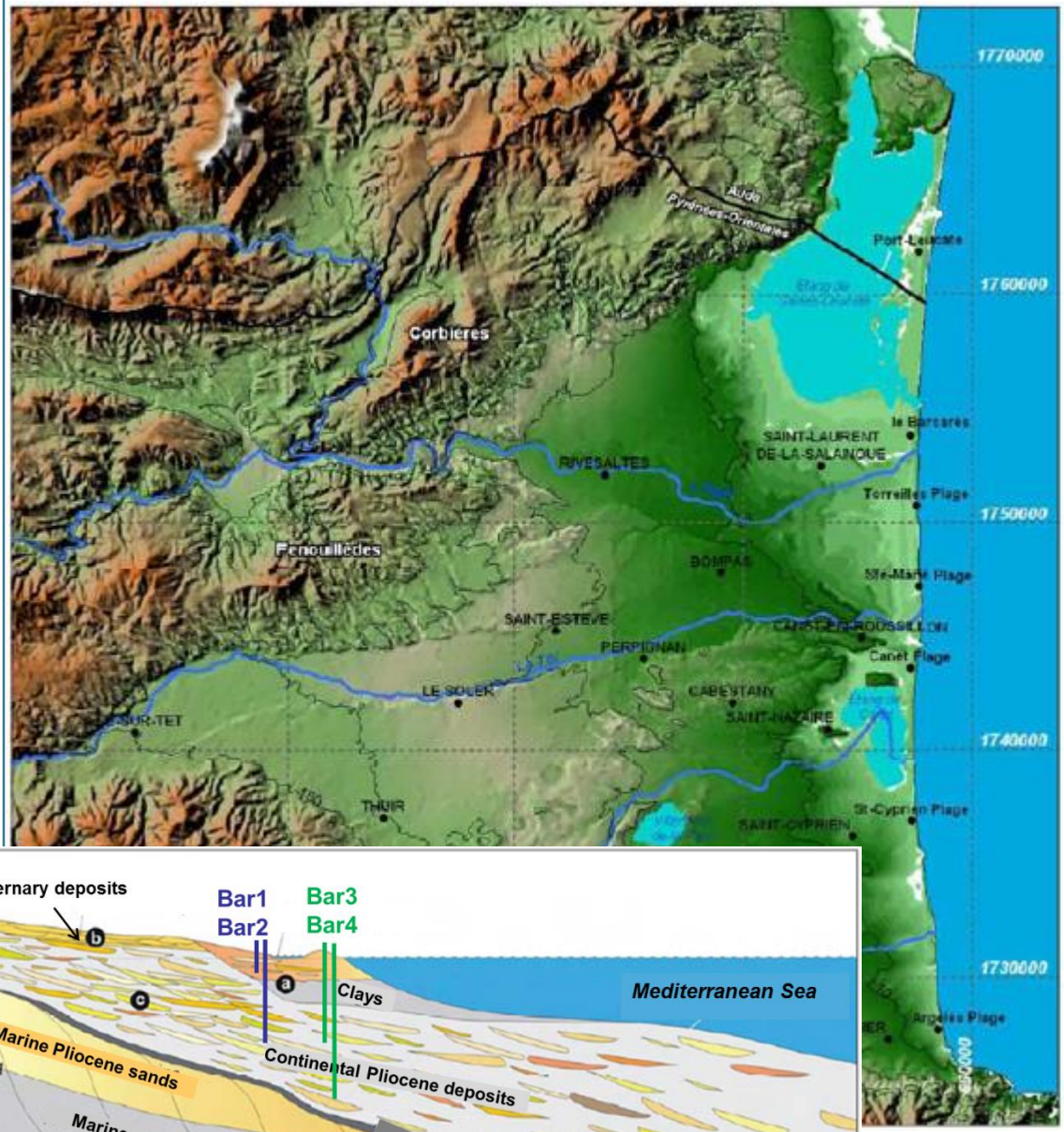
- Coastal aquifers are vulnerable water resources threatened by the increasing concentration of population density on the coast worldwide and thus the related water demand.



- Freshwater stored in coastal aquifers is particularly susceptible to degradation by seawater intrusion because of
  - increase pumping for water supply,
  - change of land-use,
  - irrigation and industrial activities,
  - in addition to climate variations or sea-level fluctuations



1st study case



- **Sedimentary aquifer of the Roussillon Basin along the Mediterranean Sea**
- **Facing seasonally increase of water abstraction**
  - Population x 10 to 20 during summer
- **Facing salinization problem**

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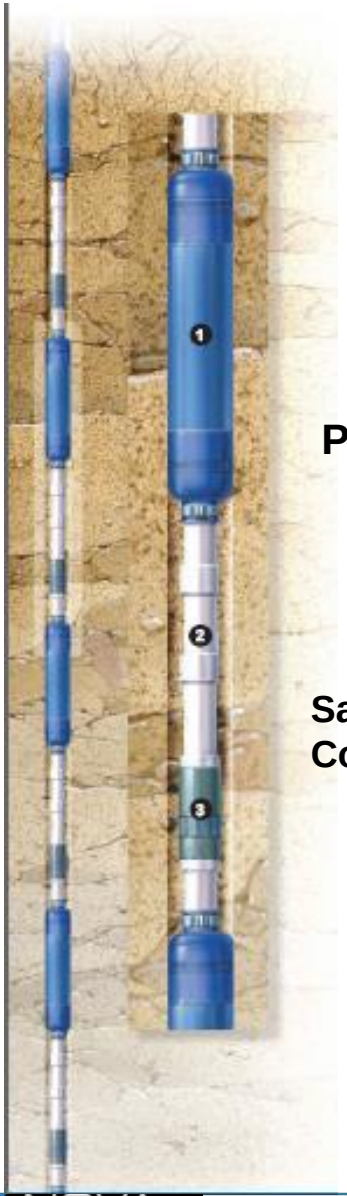
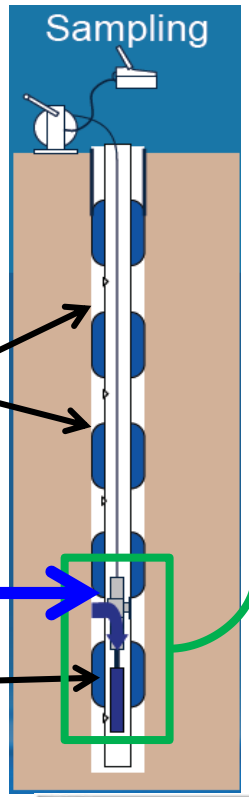
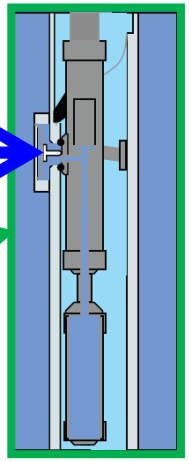
Objective

Investigate salinization along a vertical profile in this multilayer aquifer



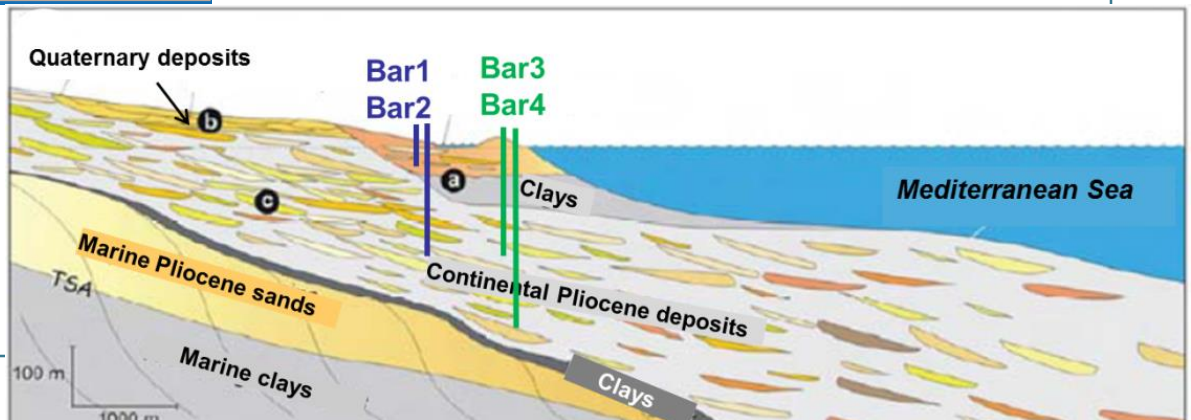




Westbay Instruments

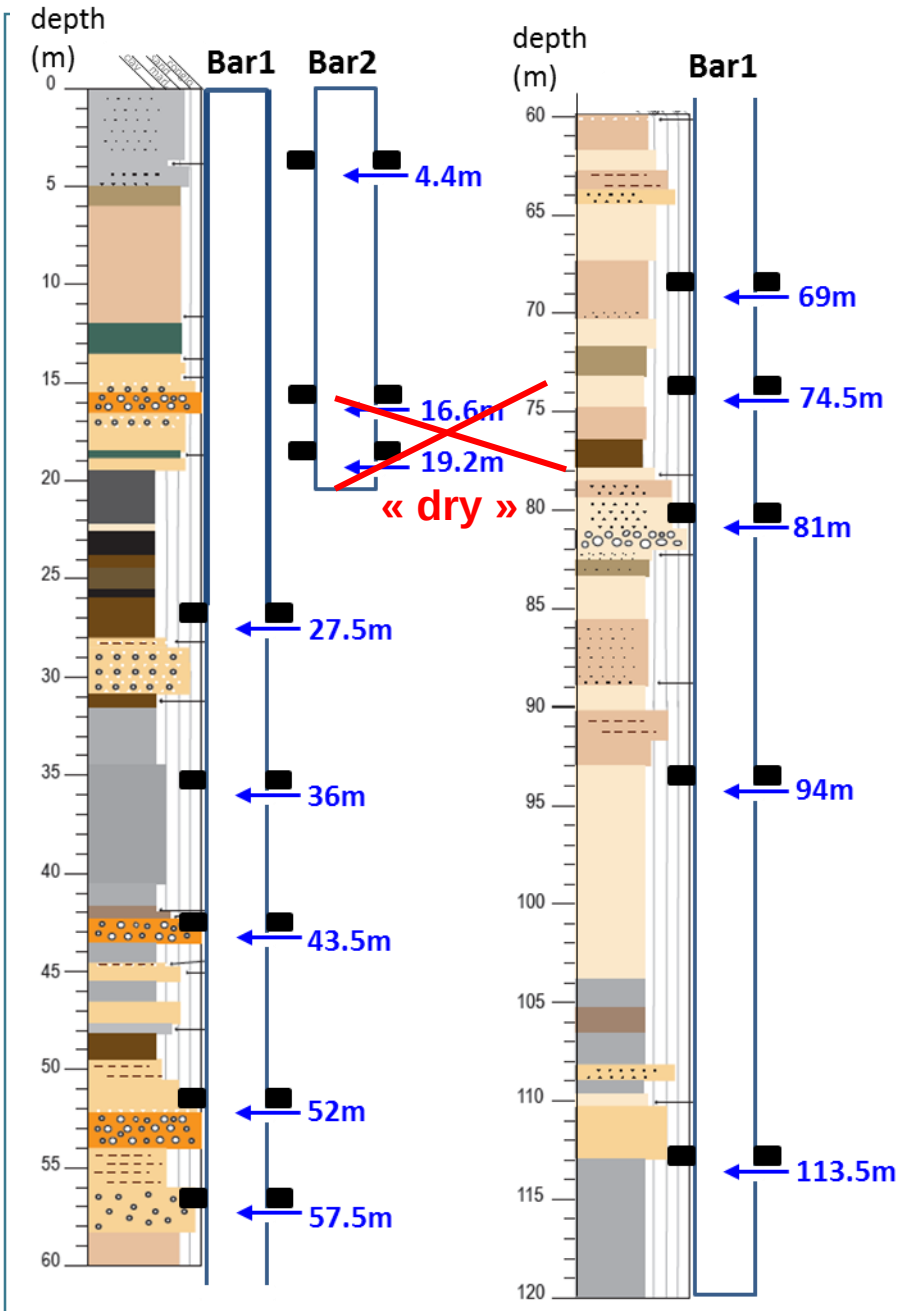
Westbay system :

- **Collect discrete fluid samples at various depth**
- **No purge necessary**
- **Open window to the aquifer**



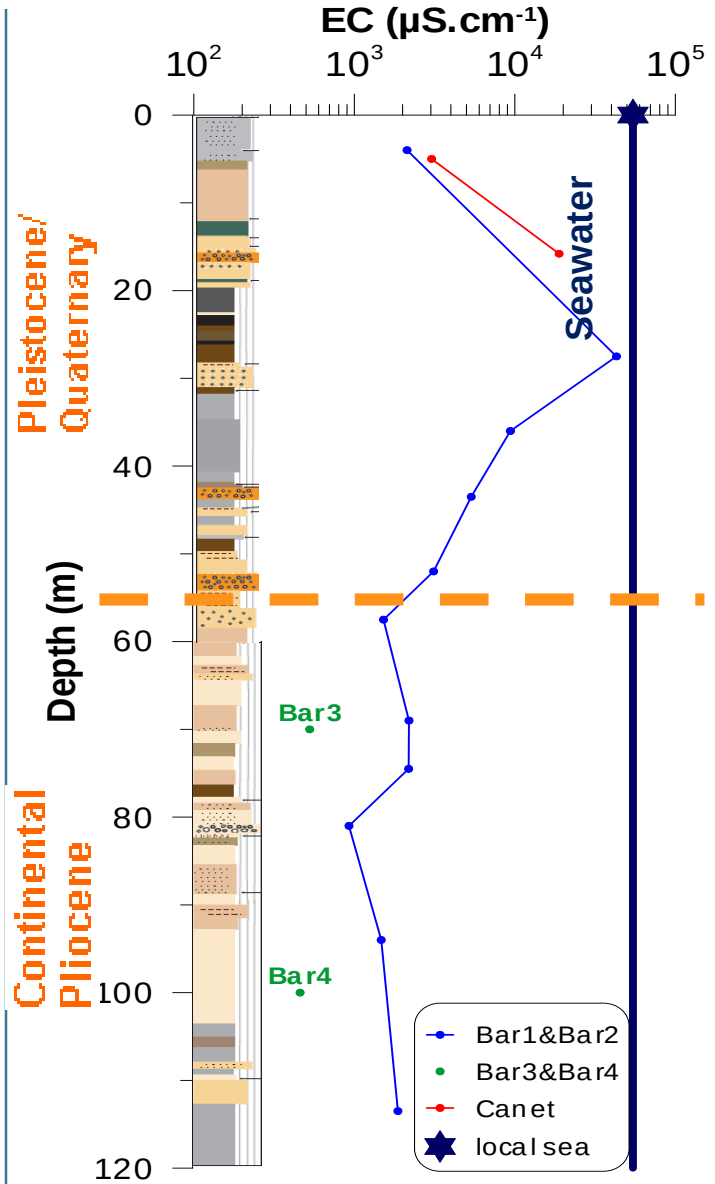
NOVA METRIX

Sampling location
Barcarès



Sampling in the **productive layers** and in the **less permeable layers** where most of the chemical processes are susceptible to take place

Vertical variation of Electric Conductivity



> **Bar1**

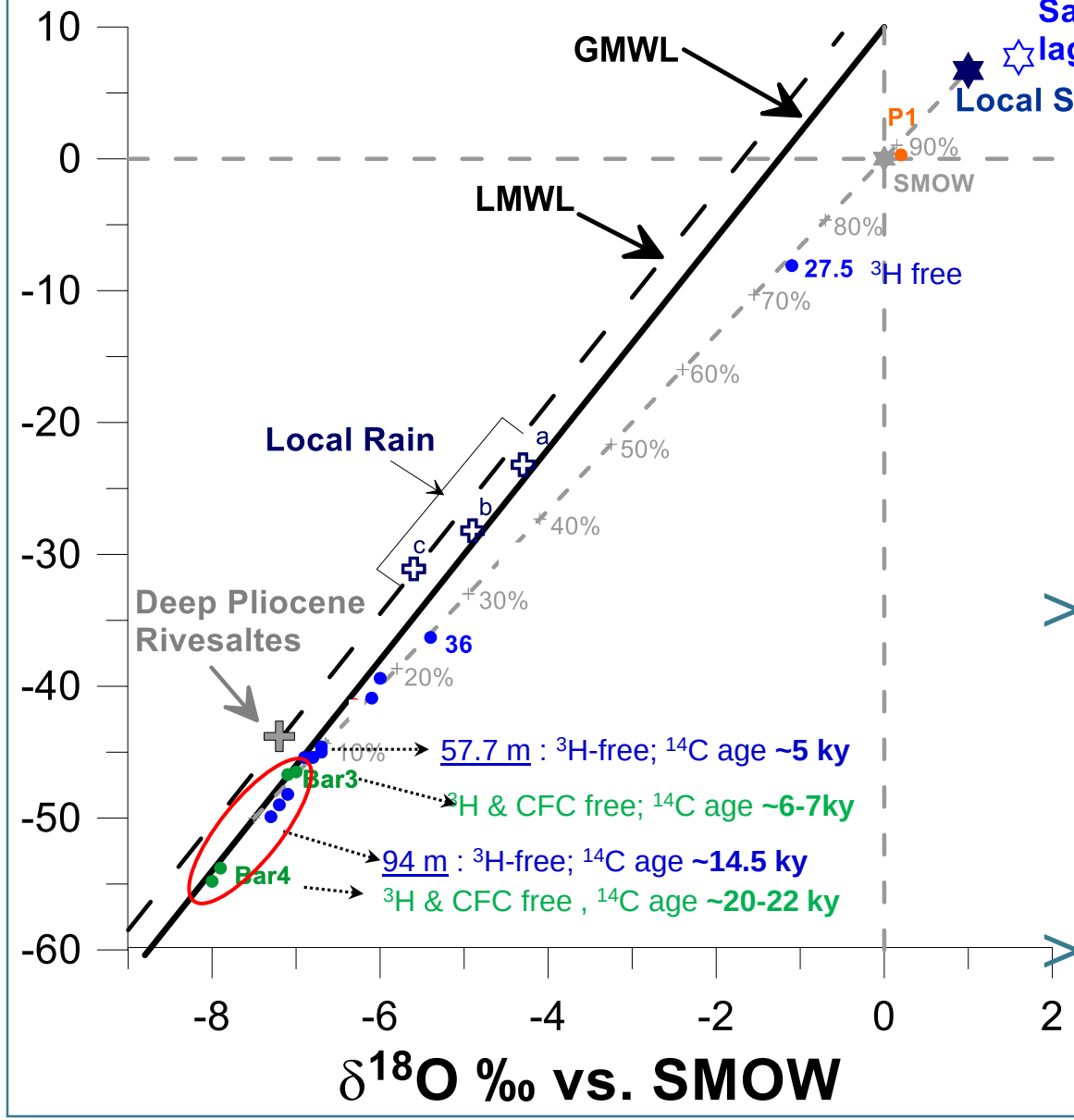
- **926 à 43 000 µS.cm^{-1}**

Up to ~ 80% Seawater EC

> **Bar3 & Bar4**

- **527 & 429 µS.cm^{-1}**

$\delta^{18}O$-$\delta^{2}H$ and dating tools



> **Mixing:**
- seawater
- Fresh component (Bar3 or Bar4)

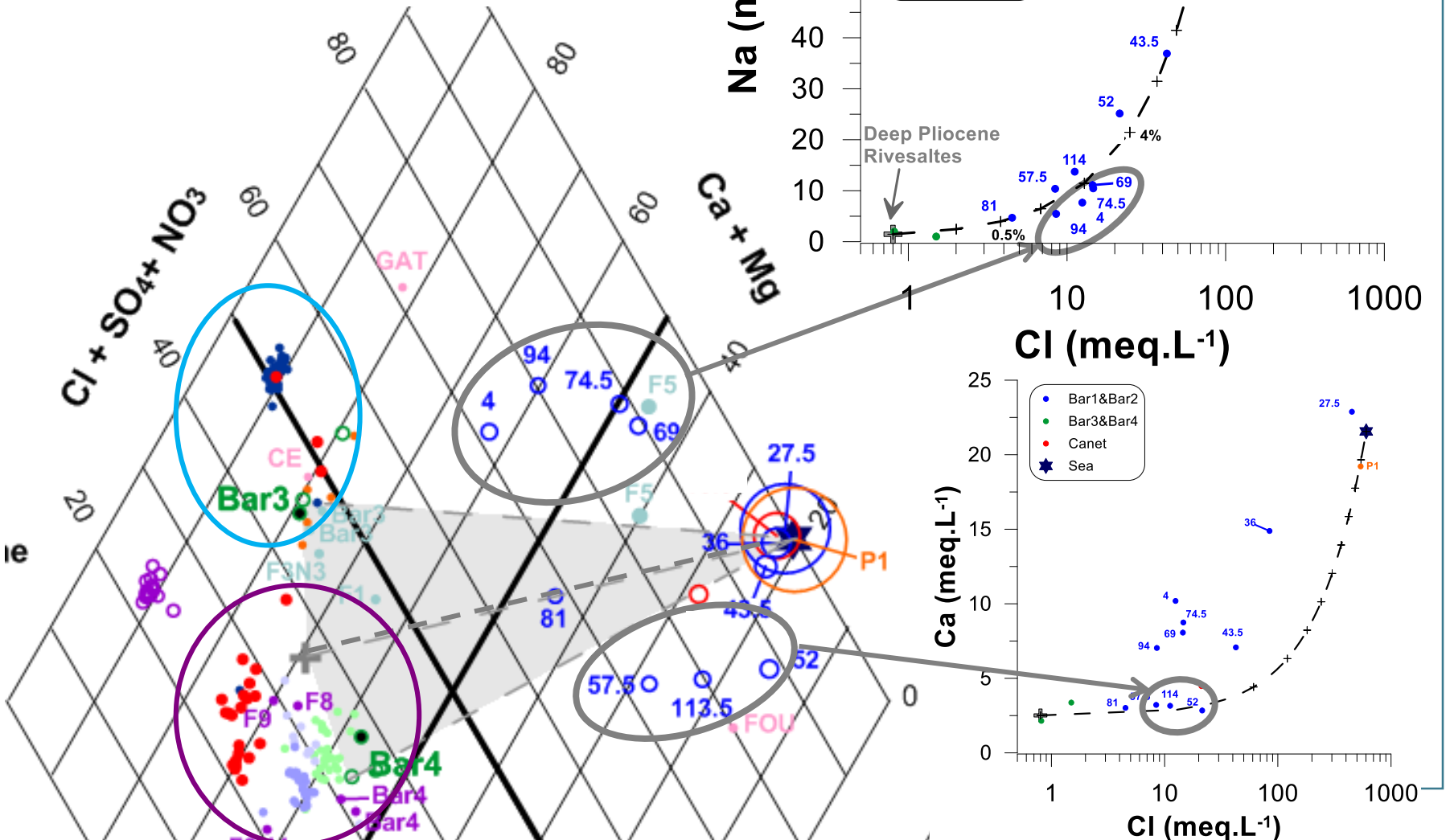
> **Salty component contribution**
- ~ 75% Bar – 27.5m

> **Fresh component**
- 5 to 20 ky

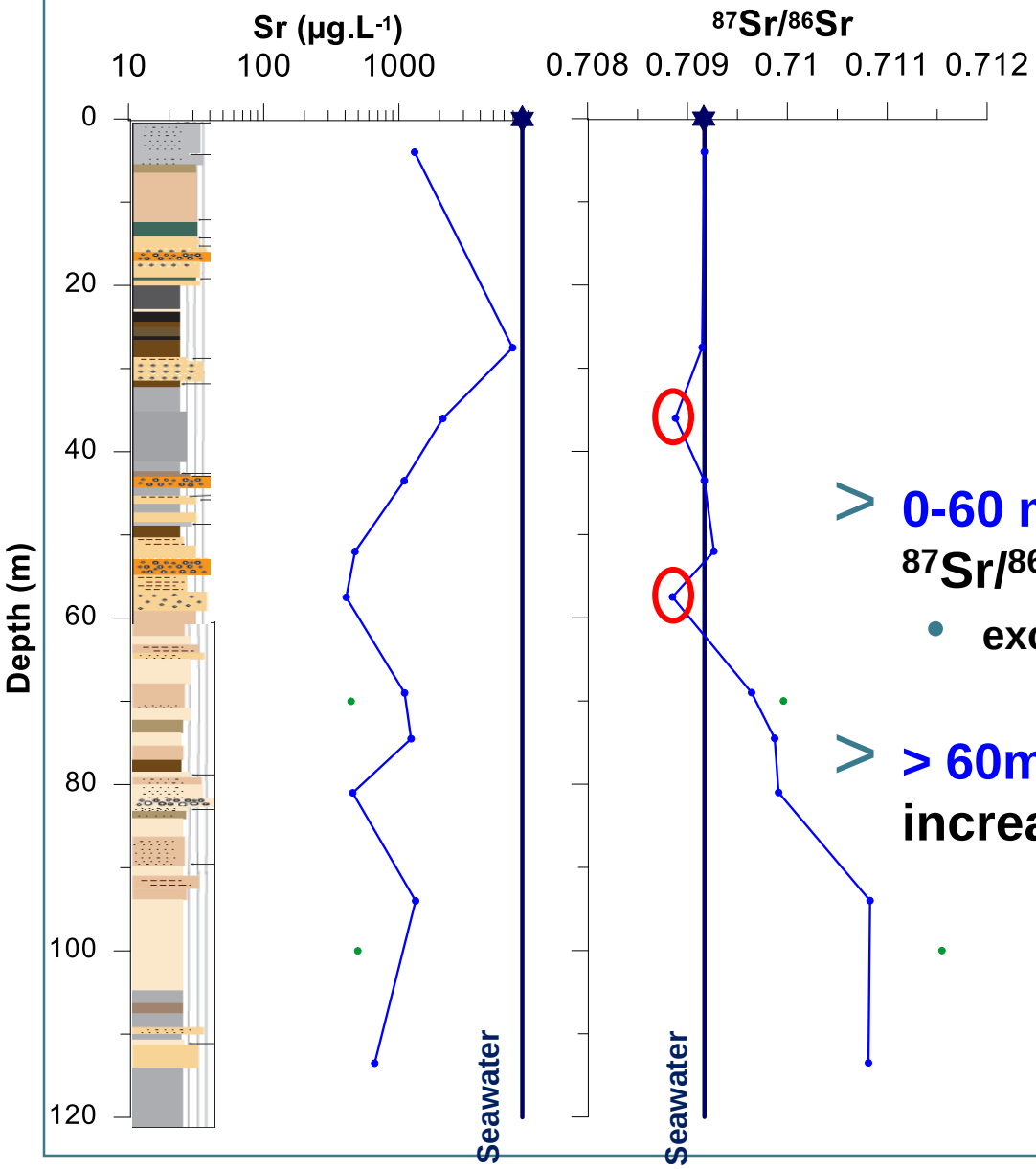
> **the high salinity (27.5m) is not related to present day seawater intrusion, nor to Salses-Leucate lagoon water intrusion**

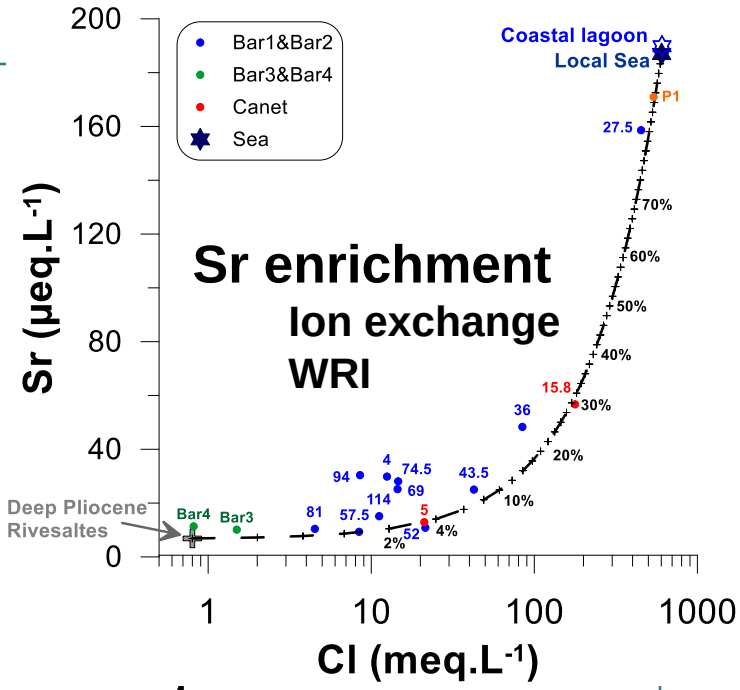
> **binary mixings between old fresh groundwater and inherited salty water**

- **Fresh component**
  - Deep Pliocene (N4)
  - Intermediaite Pliocene (N3)
- **Barcarès**
  - Na-Cl type
  - Some samples very similar to SW



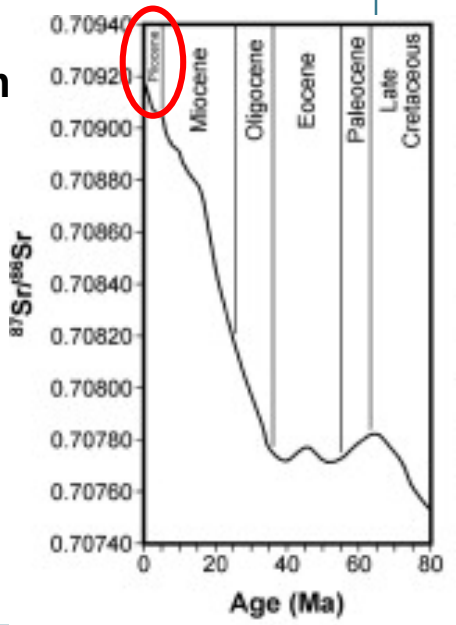
Strontium isotopes ($^{87}Sr/^{86}Sr$)



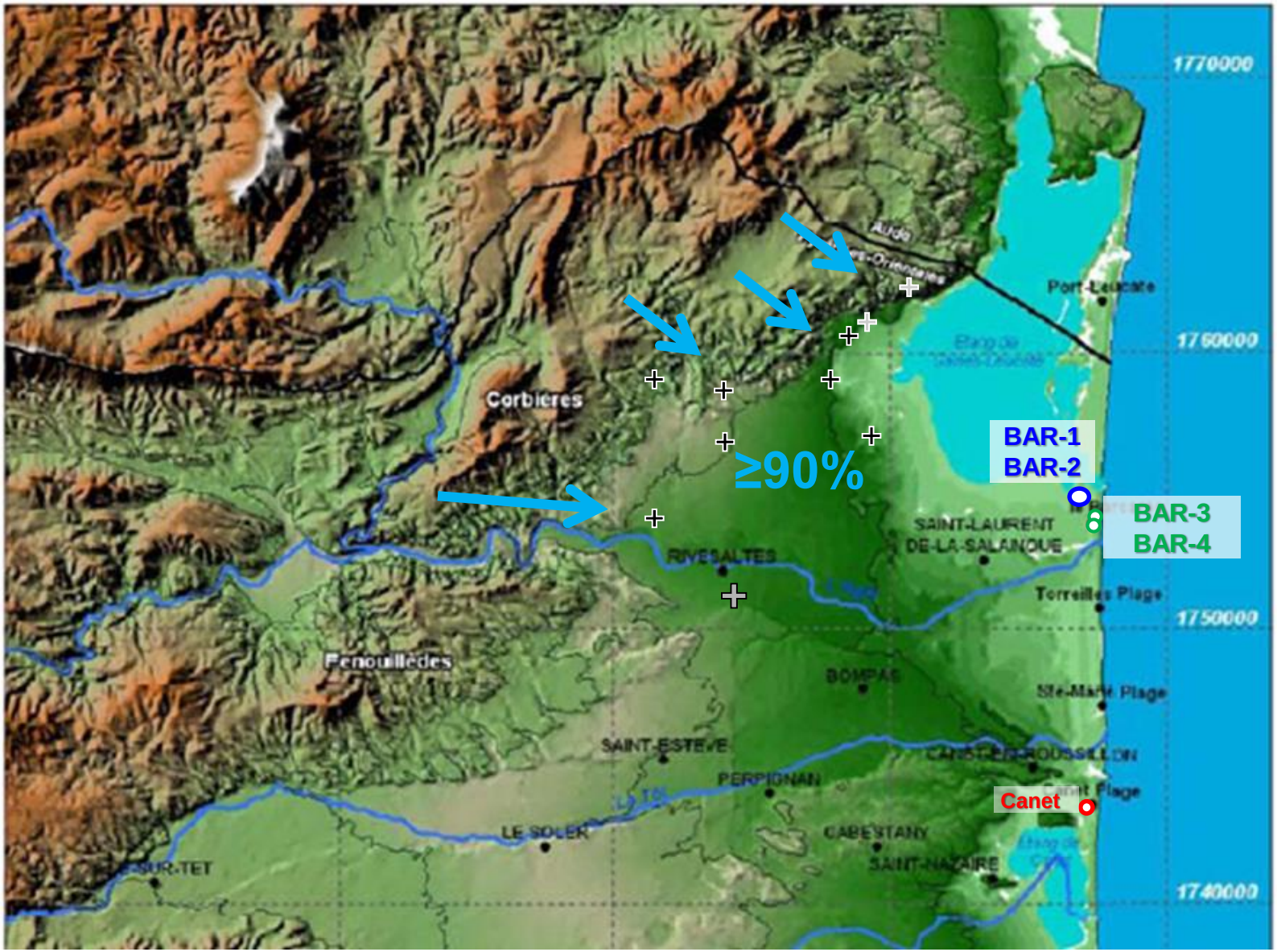


> **0-60 m : seawater $^{87}Sr/^{86}Sr$ signature**
  - **except 36 and 57.5m**

> **> 60m : $^{87}Sr/^{86}Sr$ increases**

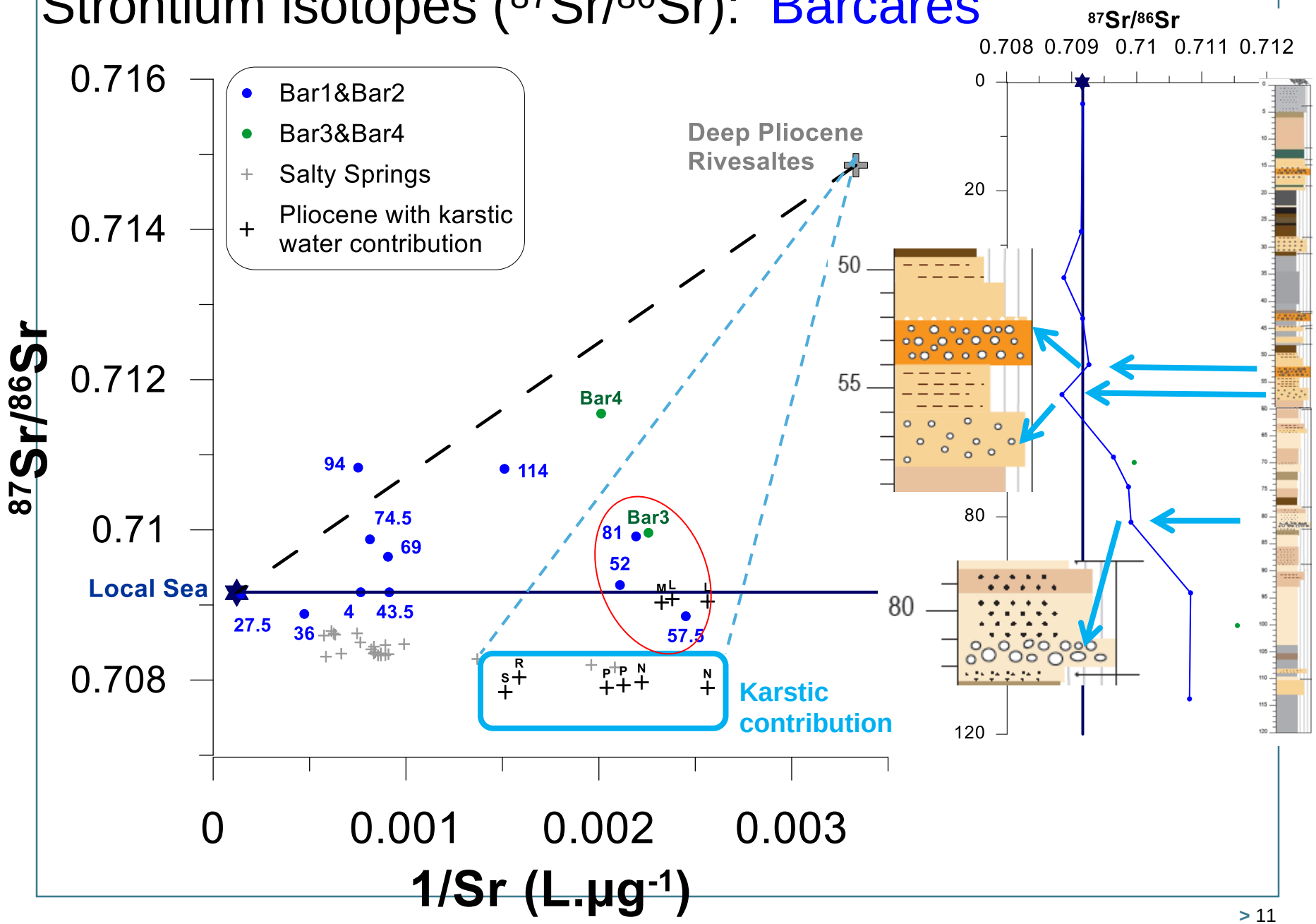


Karstic recharge of the Plio-quaternary basin



From Ladouche et al., 2004, BRGM/RP-52919-FR

Strontium isotopes ($^{87}Sr/^{86}Sr$): Barcarès



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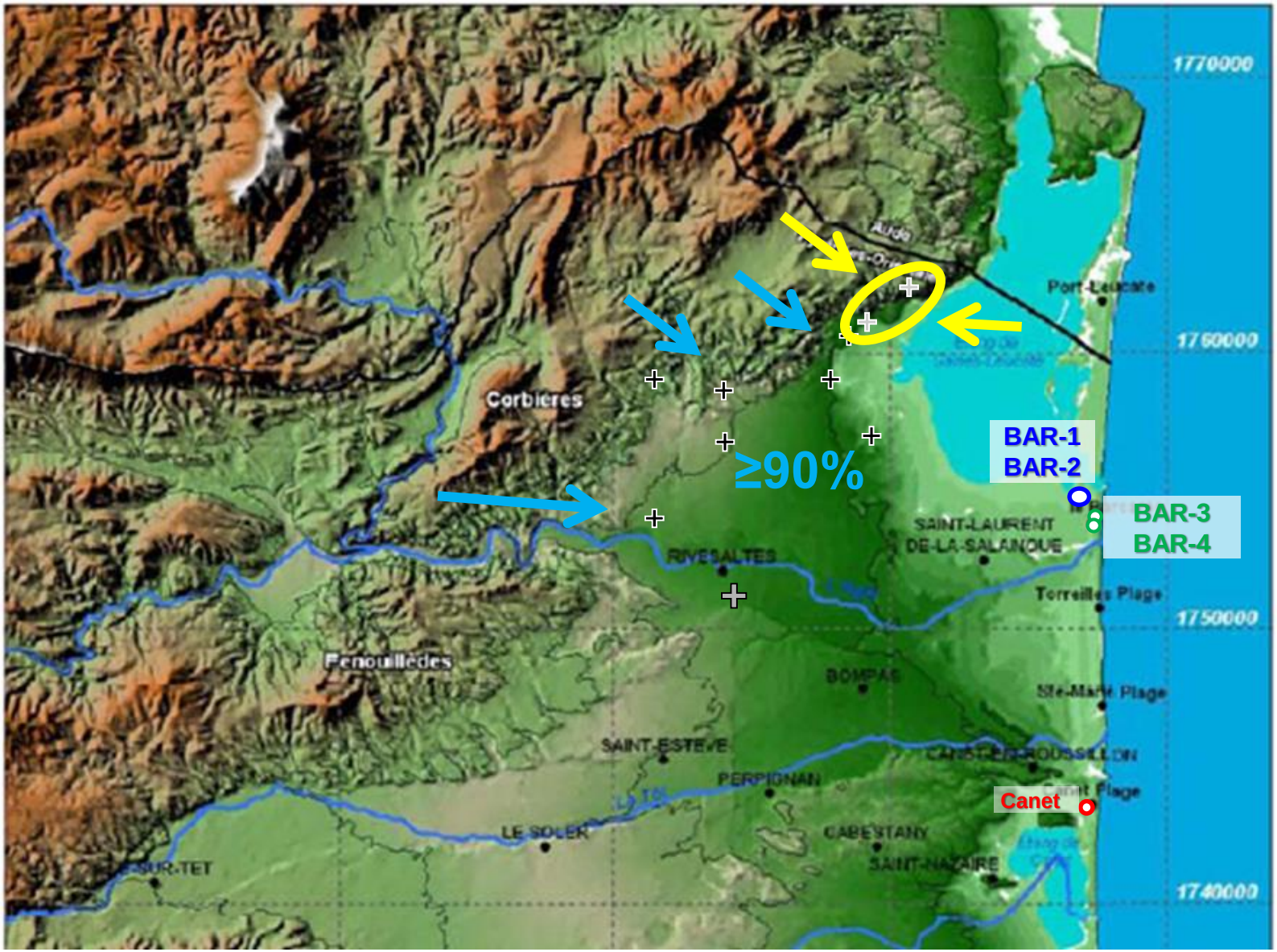

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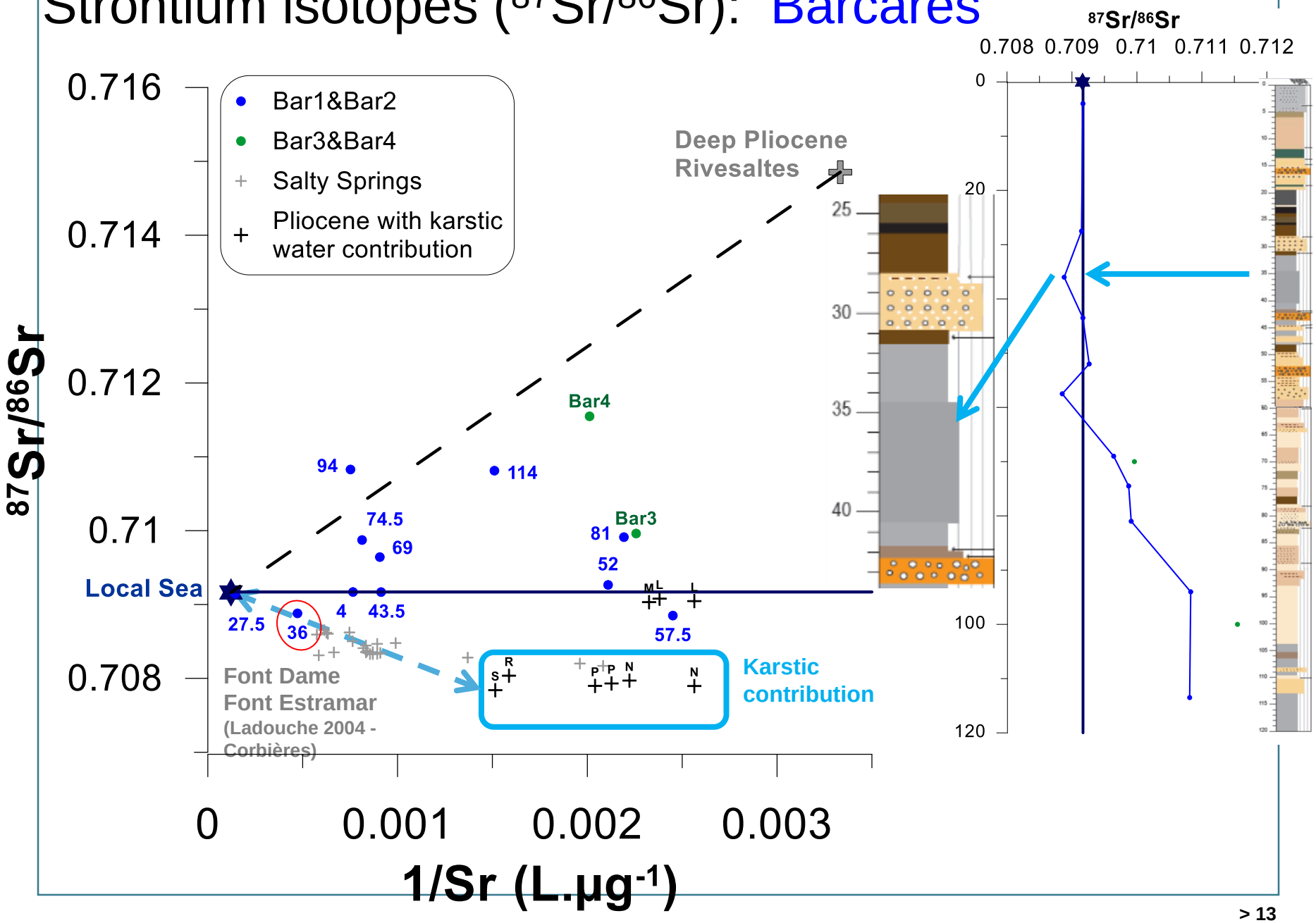

1st study case – to sum up

- Westbay system allows to sample the productive layers and the less permeable ones
-
- The Westbay sampling and multi-isotope approach allow pointing out and explaining the variation of water quality and related processes along vertical profiles

Contents lists available at ScienceDirect

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Coastal groundwater salinization: Focus on the vertical variability in a multi-layered aquifer through a multi-isotope fingerprinting (Roussillon Basin, France)

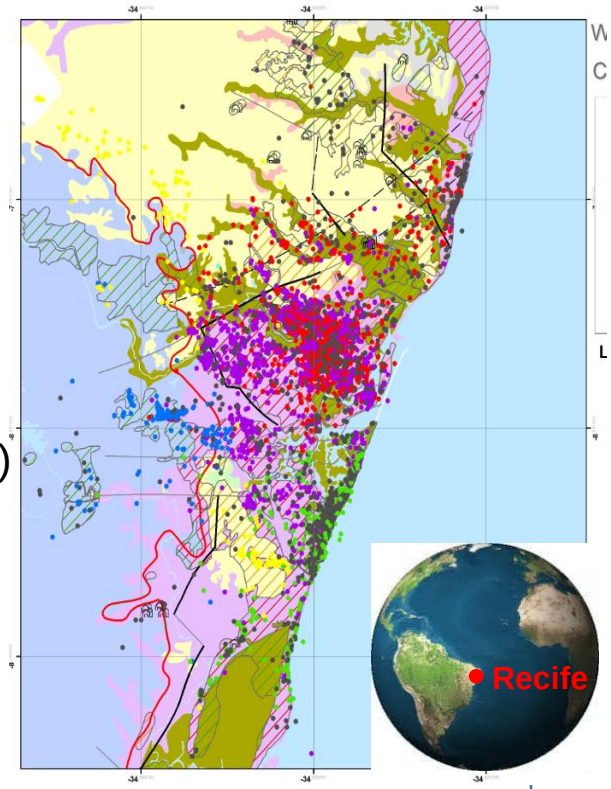
Emmanuelle Petelet-Giraud [a,*], Philippe Négrel [a], Bertrand Aunay [b], Bernard Ladouche [c], Vincent Bailly-Comte [c], Catherine Guerrot [a], Christine Flehoc [a], Philippe Pezard [d], Johanna Lofi [d], Nathalie Dörfliger [a]

2nd Study case: Recife coastal aquifers (Brazil)

Recife (RMR, **3.8 M inhabitants)** faces a serious water problems:

- **Precarious access to public water distribution** (strong contrasts in coverage, rationing for 30 years, 100 year-old)

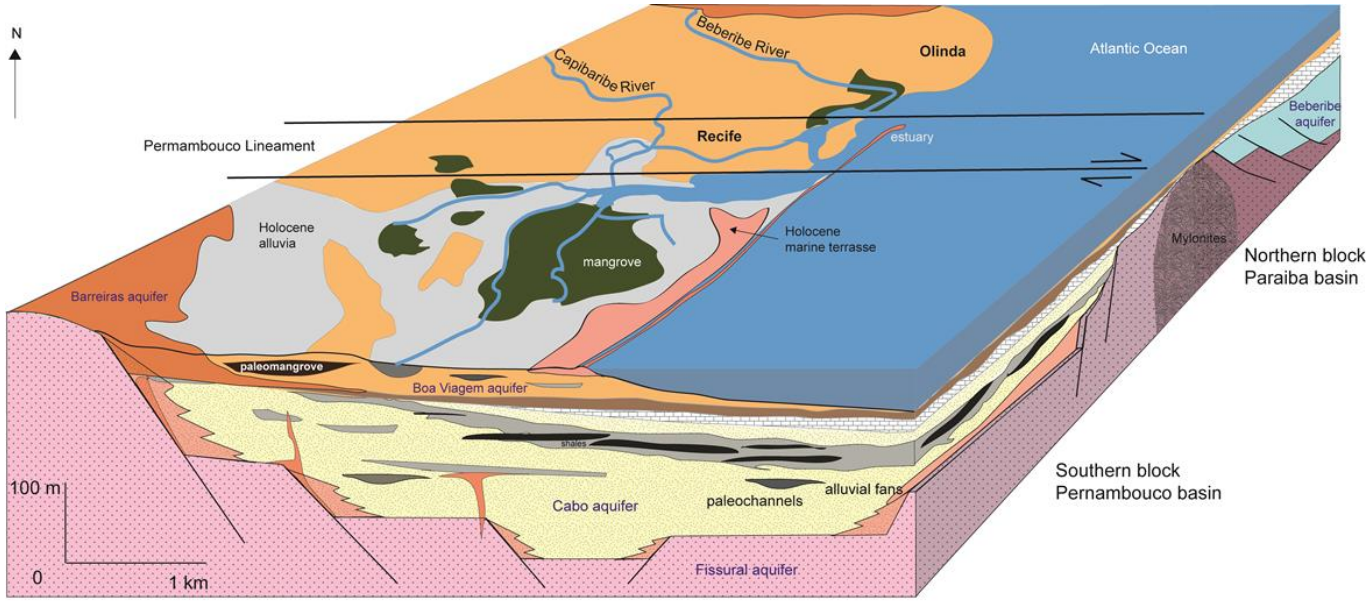
- **Severe droughts** (1998-1999; 2012-2013),
  Increase of the drilling of private wells (>15,000 today)



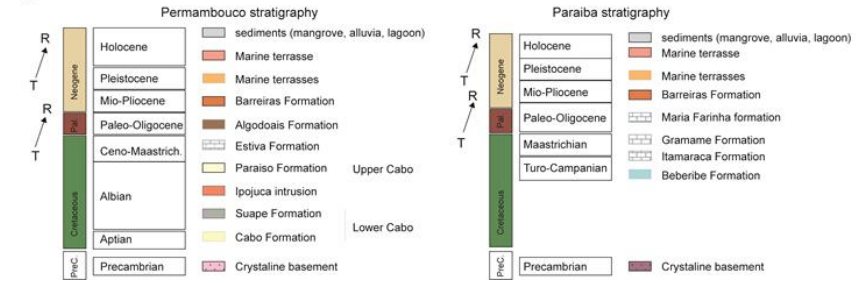
- Drastic lowering of the piezometric levels (locally up to -70m)
- Increase of salinity in deep coastal groundwaters

Study Site : geological and hydrogeological context

- Two Precambrian basements separated by a lineament : 2 basement aquifers
- Two geological basins evolving separately but both in a coastal deltaic area (northern/southern) : **2 main deep aquifers**
- Common evolution during the Tertiary and Quaternary : 2 surficial aquifers



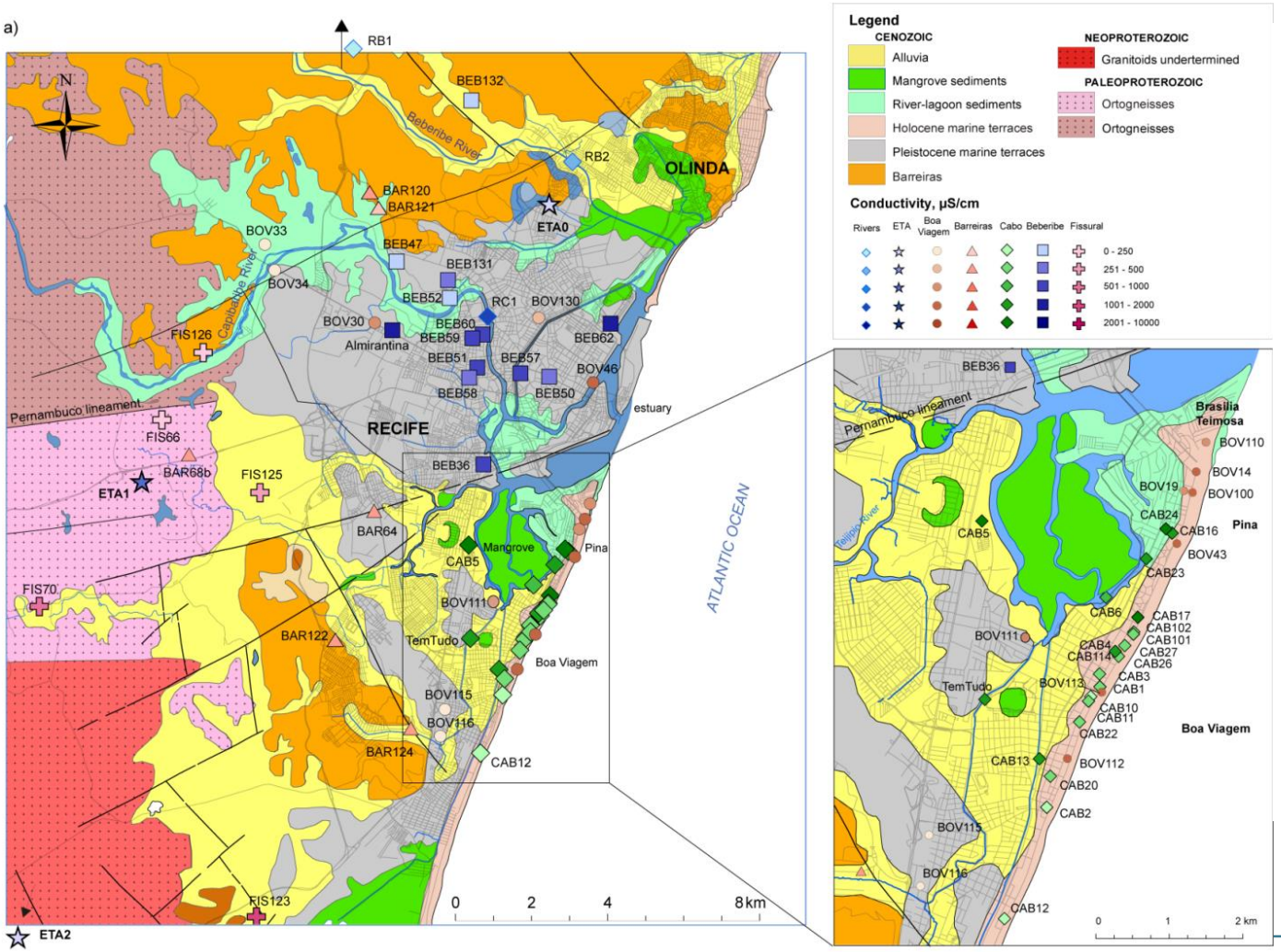
Legend



From Cretaceous to Quaternary, deltaic sedimentation, (proximal-distal)
Paleo-mangroves, Paleochannels

Material and methods

The sampling strategy aims at representing the diversity of the salinity based on previous studies



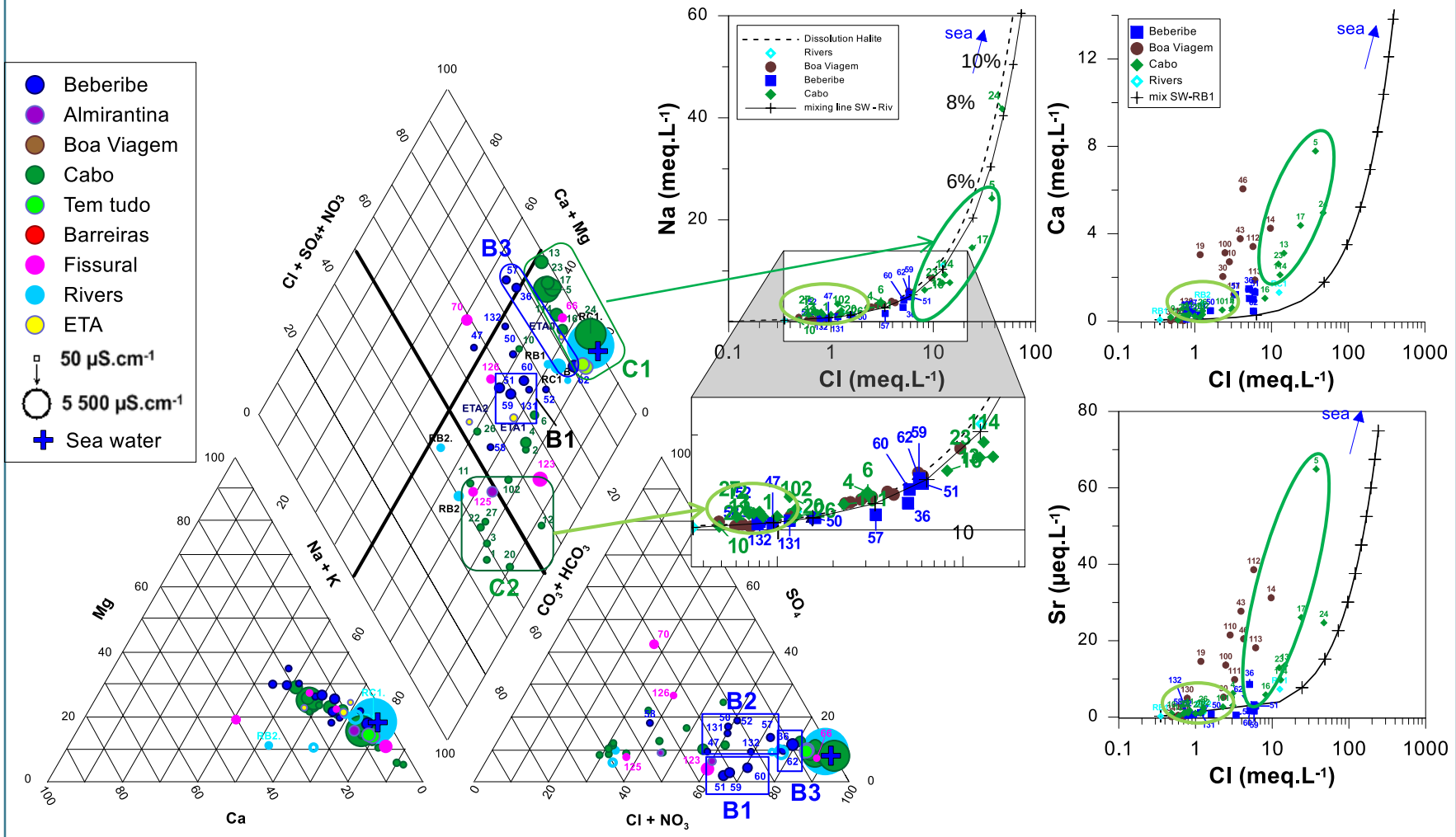
- 59 wells in 5 aquifers
- 3 surface waters

Chemistry of major and trace elements

Multi-isotope approach:
Strontium ($^{87}Sr/^{86}Sr$), and Boron ($\delta^{11}B$)

(H_2O ($\delta^{18}O$ & $\delta^{2}H$) and $\delta^{34}S$ - $\delta^{18}O$ of SO_4)

Results - Chemistry

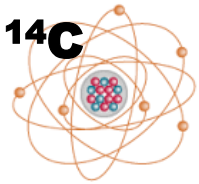


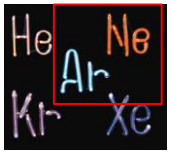
C1, **B3**: salty waters: ion exchange (max 8% mixing with salty water)

C2: Freshening, low Ca and Sr contents

Groundwater residence time

Cabo & Beberibe deep aquifers





- ^{14}C ages: **18,000 - 6,700 yr BP**
- Recharge temperature: ΔT ≈ -7°C / modern T°C

Palaeo-groundwaters : late-Pleistocene

- **Locally**, presence of CFCs – SF6 : modern end-member (Boa Viagem overlying aquifer)

Downward leakage from the overlying aquifer due to deep groundwater overexploitation

From Chatton et al., 2016. Sc.Tot.Environ

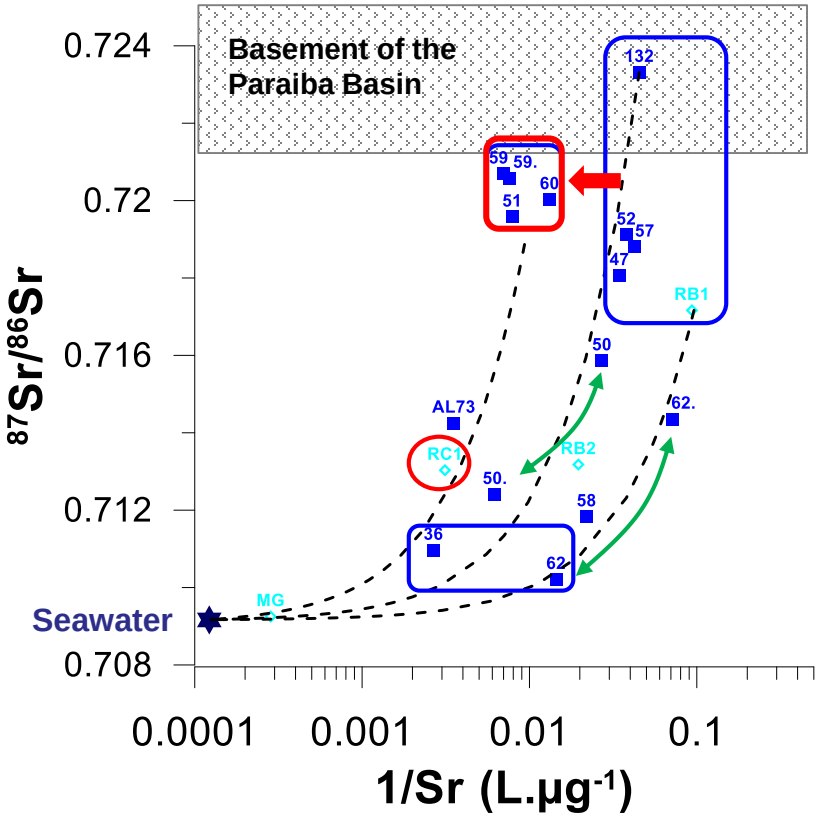
Focus on the Beberibe aquifer along the Capibaribe

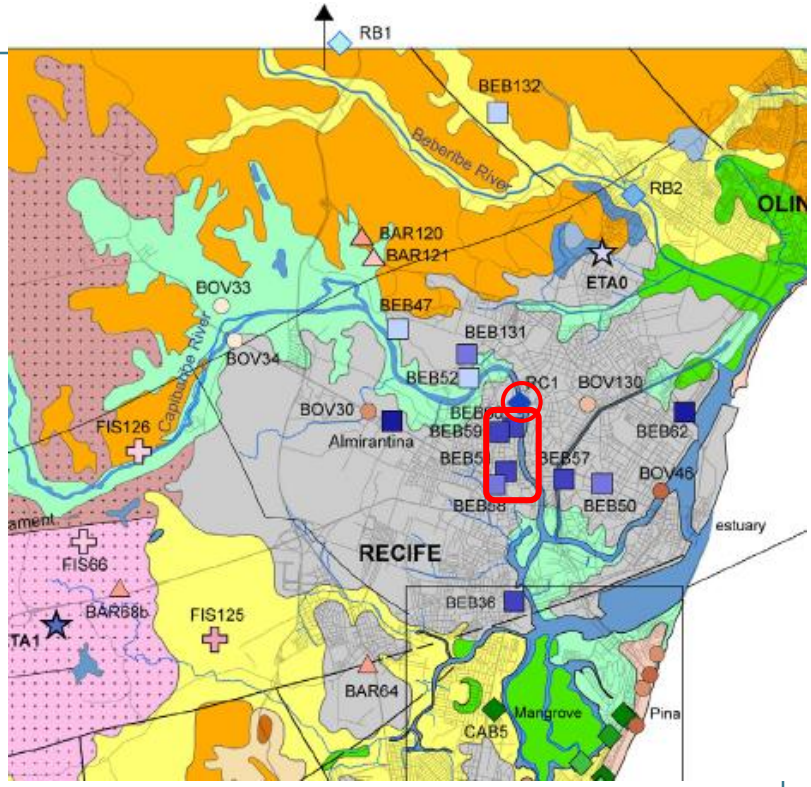
- Hydrogeologists suspected a river infiltration towards the aquifer

- Evidence of a modern component (CFC – SF6)

Beberibe aquifer

Sr isotopes



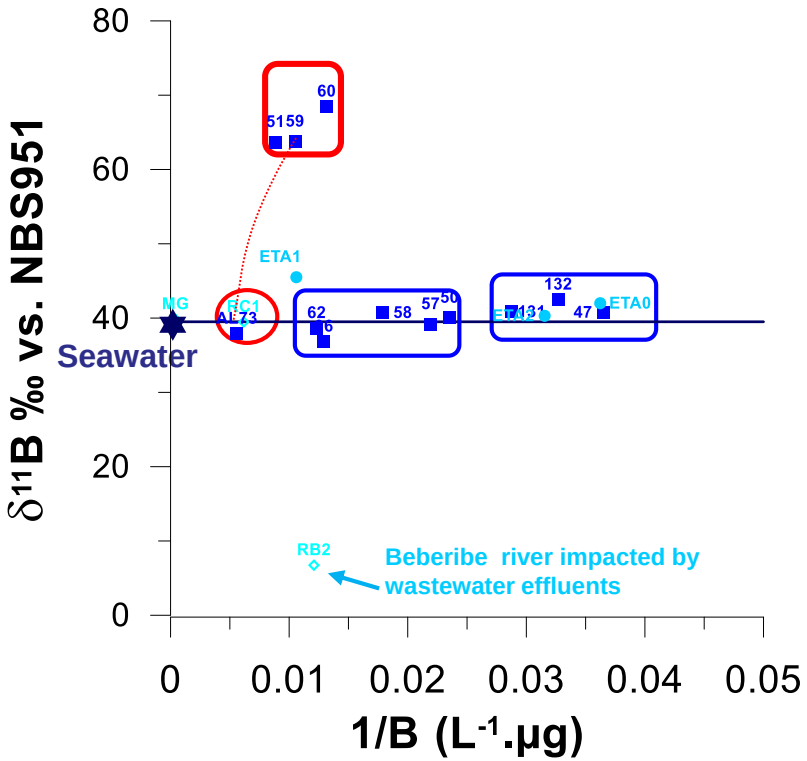


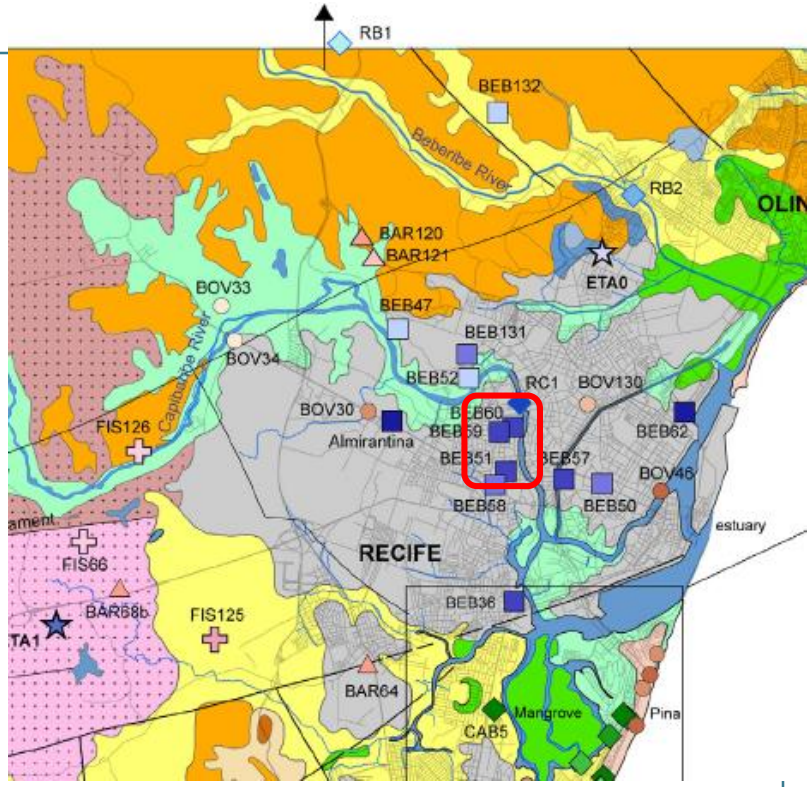
Sr isotopes do not allow to evidence surface water infiltration towards the aquifer

- water-rock interactions
- mixing with seawater
  Various mixing proportion over time

From Cary et al., 2015. Sc.Tot.Environ.

B isotopes





- **δ^{11}B signatures close the marine one**
  - Low [B] group : keeps the recharge signature
  - Medium-High [B] group: mixing of seawater with recharge signature

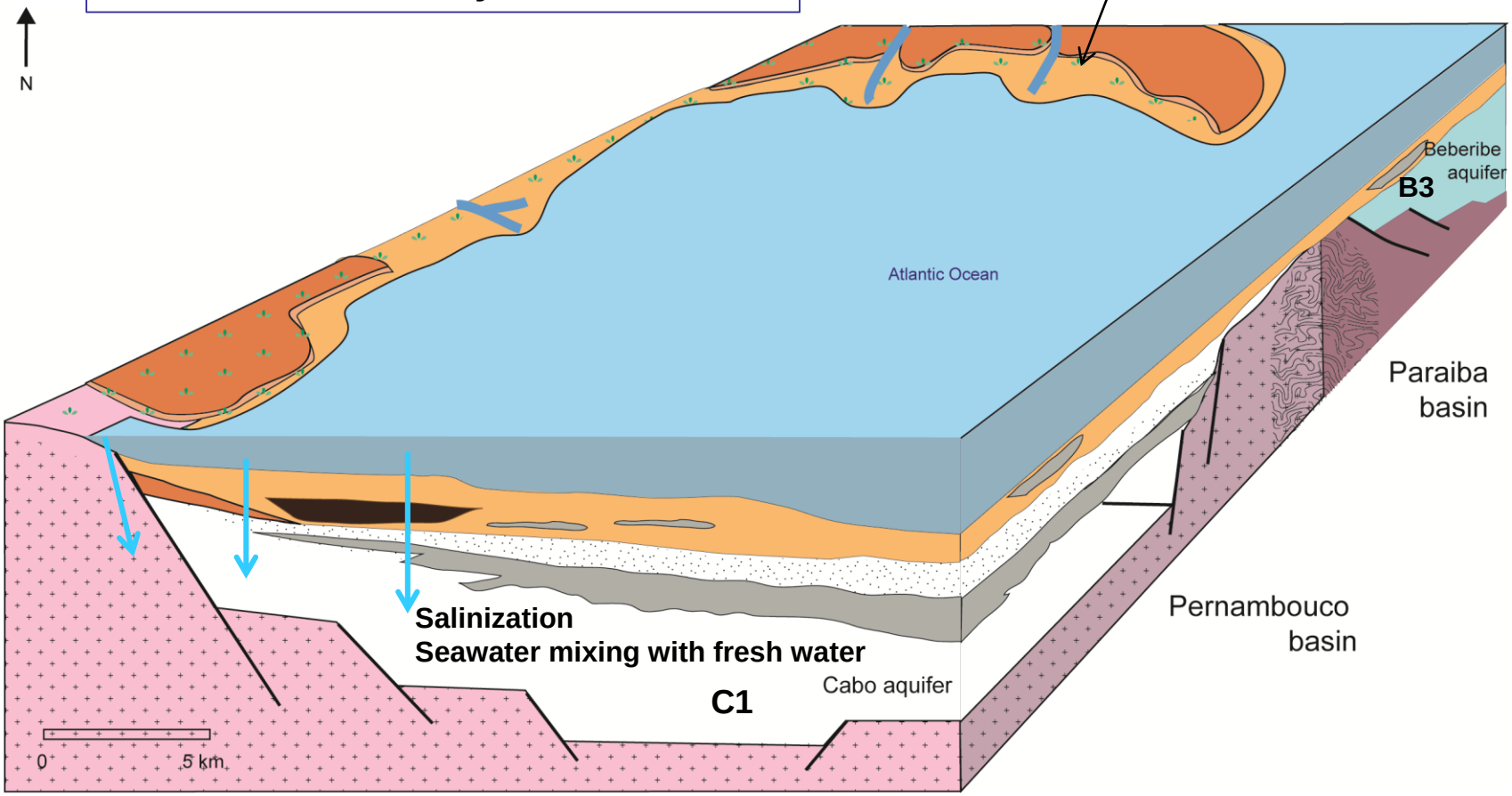
- **High fractionated values** due to ^{10}B adsorption on clays, iron oxides, and OM from a relatively B-rich water corresponding to the capibaribe River mixed with seawater (tide)

Boron isotopes allow to evidence surface water (River) infiltration towards the aquifer

From Cary et al., 2015. Sc.Tot.Environ.

Concluding conceptual model

1. Pleistocene marine transgression 123,000 y BP

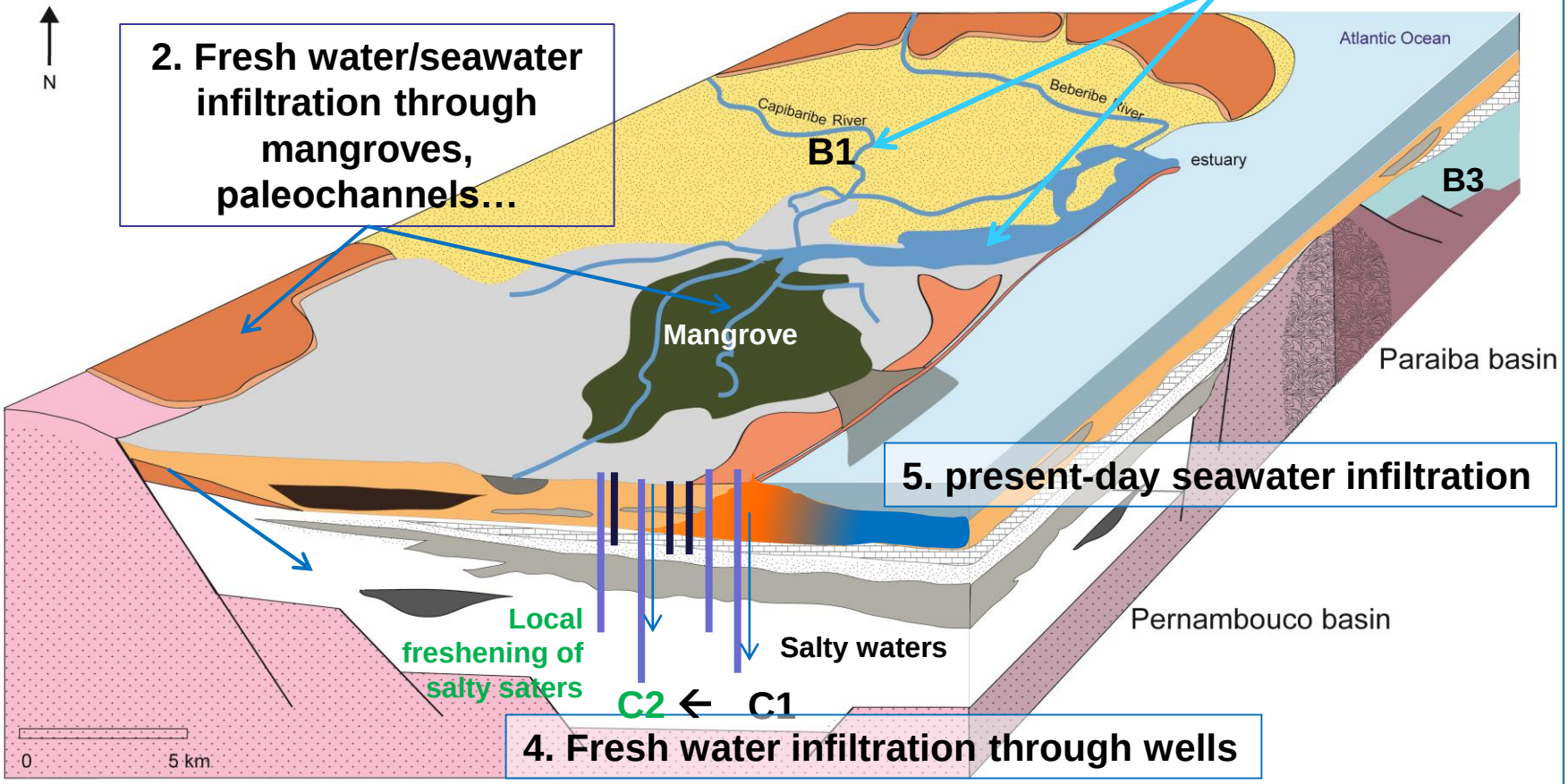


Salinization inherited from the Pleistocene transgression, present in the deep aquifers

Concluding conceptual model

Period of low marine level
Present-day urban development

3. present-day seawater infiltration through estuary and river banks



→ the new insights of the groundwater system should help the water managers to implement suistanable water resources management

Thank you for your attention