Facing geological heterogeneity impact on reciprocal coastal systems

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I. Motivation

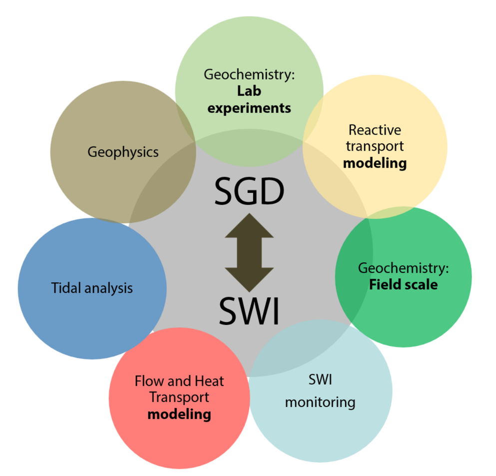
Coastal zones are increasingly demanded spots for human settlements and economic development. In these areas, aquifers are subjected to the threat of landward entrance of seawater caused by overexploitation of fresh groundwater resources. In some contexts, a coeval groundwater flow of freshwater seaward can also take place, often linked to the surficial discharge of ephemeral streams. Understand the interactions between this two reciprocal flows in coastal aquifers is needed to be able to characterize the freshwater-saltwater interface and the effects on rate of submarine groundwater discharge

1) Seawater intrusion (SWI) implies denser seawater flowing below fresh groundwater hosted in the aquifer, giving rise to a mixing zone (MZ) which thickness depends on:
(i) the movement between those masses of water
(ii) aquifer heterogeneity.

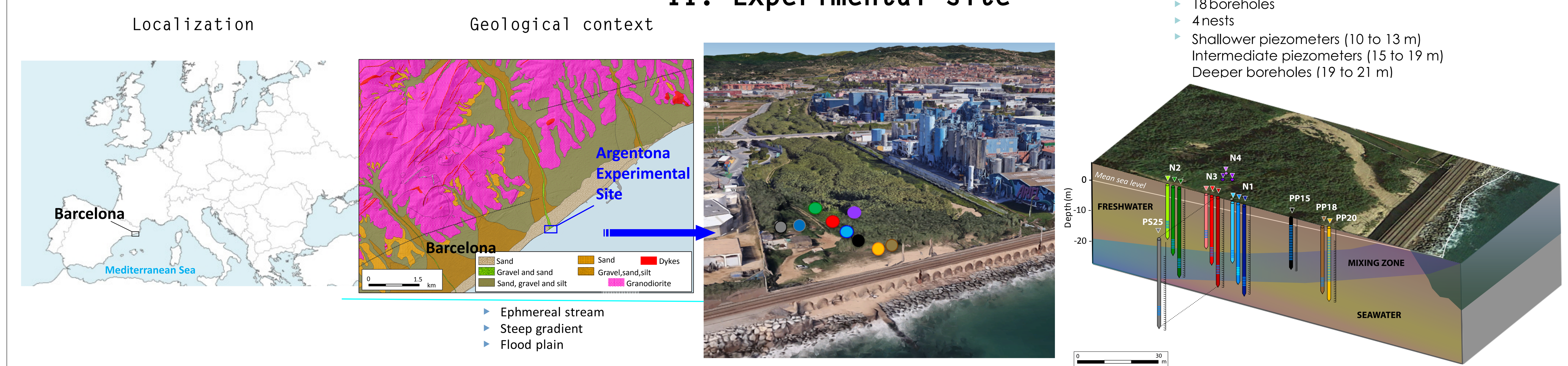
2) Submarine groundwater dicharge (SGD) occurs when there is a hydraulic connection and positive gradient between the coastal aquifer and the sea, that produces a diffuse seepage of groundwater along the shoreline.
(i) Increases the dynamics and thickness of the MZ, developing a broader region in which geochemical processes can modify aquifer matrix.
(ii) Usually characterized using radioactive tracers (^{226}Ra, ^{228}Ra, and ^{224}Ra) which spatial variability within the aquifer needs to be better characterized.

To fully understand the mechanisms involved when SWI and SGD collide, all the different types of geological, hydrodynamical and hydrochemical datasets should be integrated. Small scale features must also be taken into account to explain observed behaviors at bigger scales. And to achieve that, hierarchical methodologies focused on real world aquifers characterization taking into account those scale-dependence and derived heterogeneity effects, are required (Werner et al., 2013).

Define a conceptual model of a real aquifer that integrates the geological, petrophysical hydrodynamical and hydrochemial aspects



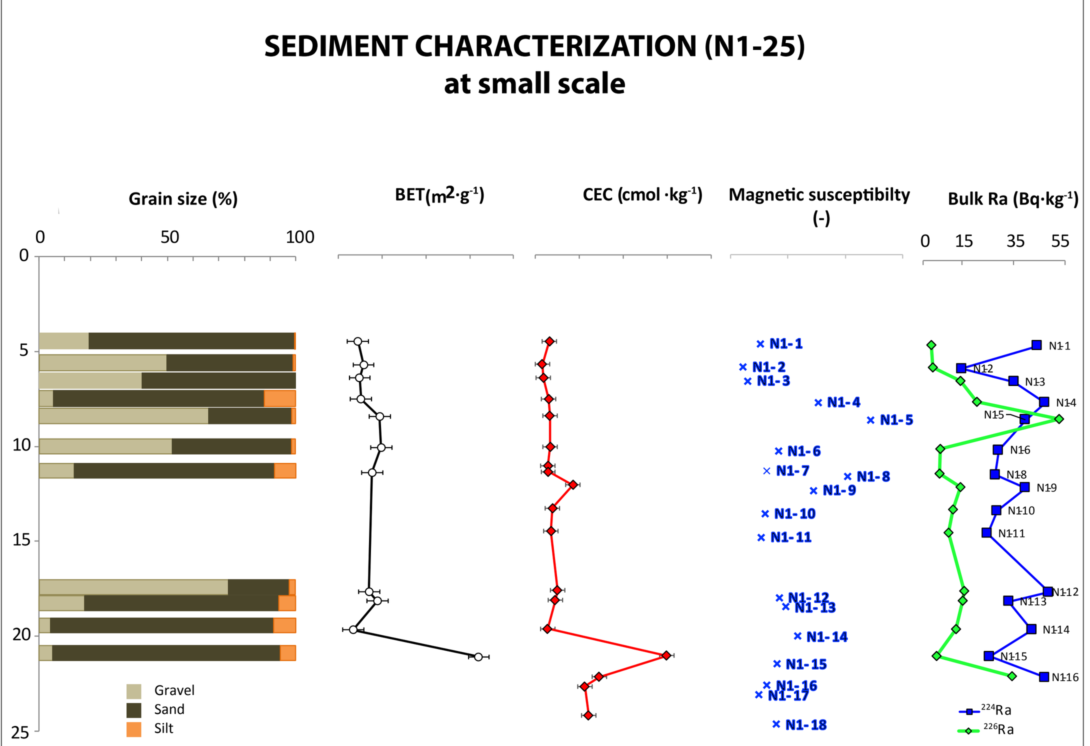
II. Experimental site



- Alluvial coastal aquifer where SWI and SGD takes place and the occurrence of radium and radon as natural tracers is relevant (Cerdà-Domènech, 2017).
- Multidisciplinary field laboratory located in the Maresme region, northwest Barcelona (Spain), close to the mouth the temporary stream of Argentona.
- Heavily instrumented piezometers: electrical resistivity electrodes The followed methodology implied building a dedicated experimental site to be able to monitor changes in the freshwater saltwater interface, and variations in the rate of SGD.

III. Results

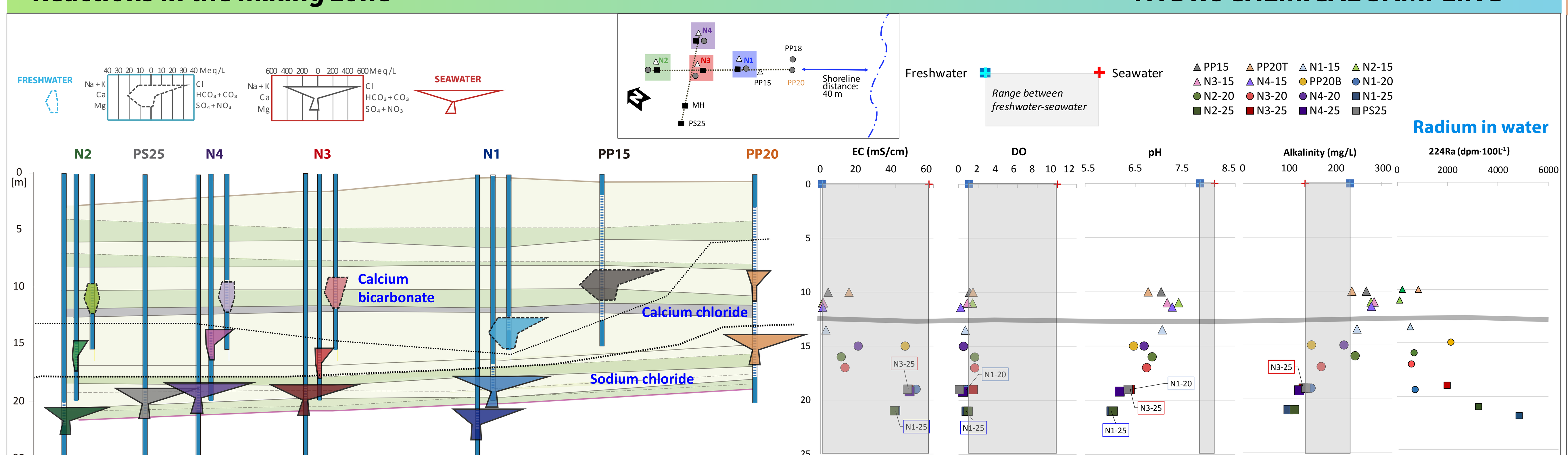
Radium distribution — CORE SAMPLING



Localization of ion-exchange reactions

In the upper part of the aquifer, **surface area** is lower, corresponding to the coarser materials identified during **grain size** analysis. Towards depth, surface area increases, affecting **CEC** values. At 12 m depth there is a slight increase in CEC, that we attribute to the silt layer identified in the analysis performed at bigger scale. ^{226}Ra presents its maximum value when magnetic susceptibility (MSUS) is higher, and also in depth.

Reactions in the mixing zone — HYDROCHEMICAL SAMPLING



Sampling performed in 16 piezometers drilled at 3 different depths, with 2 m of slotted interval to avoid mixing of waters from different hydrogeological units

Assess changes in groundwater composition

In all the deeper boreholes **sodium chloride** water is dominant, whereas in the intermediate piezometers sodium is scarce and **calcium chloride** water is dominant. The nearly absence of Na in the MZ indicates the huge ionic exchange that is taking place.

Parameter evolution with depth

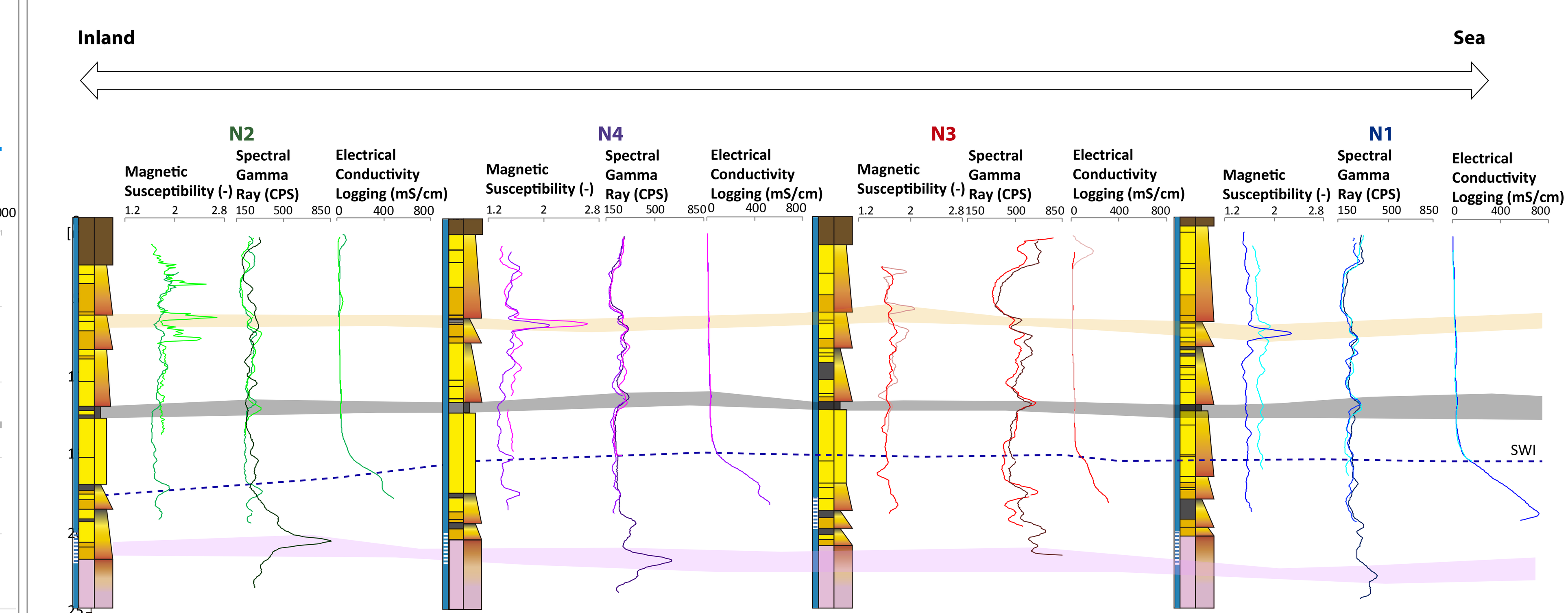
EC tends to increase with depth as expected. However, the piezometers closer to the coast, between present higher EC than the deeper piezometers. **DO** is lower in the deeper boreholes. Values of **pH** are much lower than the range between freshwater-seawater and tend to decrease towards depth, showing an increasing acidification in the lower part of the aquifer.

Characterize the mixing zone

The Mixing Zone (**MZ**) presents 4 m of thickness, starting at 15 m depth, and a higher position closer to the sea. Towards inland, the upper boundary decreases.

In the shallower boreholes, **Ra activity** tends to increase when salinity is higher, but the reverse behavior can be found in the intermediate and deeper boreholes, highlighting the heterogeneous distribution of Ra within the aquifer.

Geological and geophysical characterization — DOWNHOLE GEOPHYSICS



All the wells surveyed present an isolated increase in **MSUS** at around 7 m depth, more pronounced in N2-15, N4-15, N4-20 and N1-20. In N2-20 and N4-20, another slight increase can be found at 17 m depth.

Around 12 m depth, a peak can be distinguished in all the boreholes, indicating the presence of a laterally continuous layer of fine grained material (**silt**) previously identified with core analysis.
In the lower part, there is a general increase in the total **SGR** counts caused by the presence of sands with fine-grained granitic matrix coming from the upper part of the basement weathering front. The following decrease is due to the presence of non-matrix supported granitic sands.

ECL presents an increasing trend towards depth.
The sharp increase at 15 m depth results from the higher pore water salinity due to the entrance of SW through permeable layers with higher grain size.

IV. Discussion

- There is a sharp increase in all the SGR logs at 21 m depth, together with the increase in BET surface area and CEC measured in a sample extracted at the same depth. This increase could be related to the localization of a thin alloteritic layer of saprolite that is representing the upper boundary of the weathering front of the granitic basement, with high content in clays.
- Hydrochemical analysis showed a constant anomaly in most of the parameters measured in N1-20. The different types of behavior at this depth may be due to the possible existence of a preferential flow path or a more continuous silt lens that traps the movement of saltwater. The electrical conductivity of the formation ($C_0 = C_w/F + C_s$) at this point experiences a sharp decrease. The dependence of this parameter with the surface conduction (C_s) can be significant and needs to be assessed taking into account the variations in the formation factor (F) as a result of the presence of different lithologies.
- The observed variations in Ra can be due to the different pH values (Ra activity increases linearly with lower pH) or to the rate of production (alpha recoil) within the aquifer. For the intermediate and deeper boreholes, radium activity decreases with increasing salinity. This anomalous decrease could be related with zones in the aquifer exposed to higher flushing of waters in the depleted wells (PP20, N1-20 and N3-20), and to the presence of an extra source of Ra in the enriched wells (N1-25 and N2-25), as highlighted by the measurements performed on core, that are also exposed to lower pH conditions.

V. Conclusions

- We can distinguish an upper part (up to 6 m depth) formed by coarser materials with sandy matrix, an intermediate continuous silty zone around 12 m depth, and a lower alternation of coarser and finer sands, with an increasing granitic component towards depth.
- The role of the silt layer identified with the geological and geophysical techniques as an aquitard, was confirmed merging the information obtained with core analysis and logs with hydrodynamical techniques (poster A.285). This confining layer has proved to have a direct impact on the hydrodynamics of the aquifer, but also may be affecting the distribution of hydrochemical parameters with depth.
- The mixing zone was characterized using geophysical logging, and hydrochemical sampling. Results were compared with the geological observations made on core, to be able to explain the variations in electrical conductivity logging.
- The integration of different types of logging techniques must be considered carefully in order to avoid signal interferences and ensure good quality data. Electrical resistivity tomography equipment installed along the boreholes, affects the signal registered by magnetic susceptibility and avoided data processing for the deepest boreholes of each nest (N1-25, N2-25, N3-25 and N4-25).
- Logging techniques provide an information in parts of the aquifer where hydrodynamical and hydrochemical characterization techniques cannot be applied because of the absence of shallower piezometers.

VI. Future works

- Analyze and model Radium behaviour using data from long term sampling campaigns (2 years monitoring) to characterize Radium behaviour within the aquifer and quantify SGD.
- Perform laboratory experiments to characterize controls on Ra desorption from the recovered sediment, to be able to explain the observed anomalous relationship with salinity.
- Unveil the confning effect and the connectivity of the finer layers identified in the geological description (see poster A.285 Hydraulic and mechanical characterisation of tide-induced head fuctuations in coastal aquifers).
- Calibrate electrical conductivity logs taking into account CEC and mineralogy.
- Geochemical modelling of the hydrochemical sampling campaigns to quantify geochemical activity in the MZ

Complementary info can be found at...
A.285 - Hydraulic and mechanical characterisation of tide-induced head fluctuations in coastal aquifers
A.287 - Distributed temperature sensing to monitor the fresh/salt groundwater interface
A.280 - Does groundwater data from piezometers correlate with FO-DTS and CHERT in coastal aquifers?
Tue, 09 Apr, 17:15–17:30 Room 2.31
A long-term experiment for monitoring saltwater intrusion dynamics using time-lapse cross-hole ERT

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