

Paleo-hydrogeological evolution of a fractured-rock aquifer following the Champlain Sea Transgression in the St. Lawrence Valley (Canada)

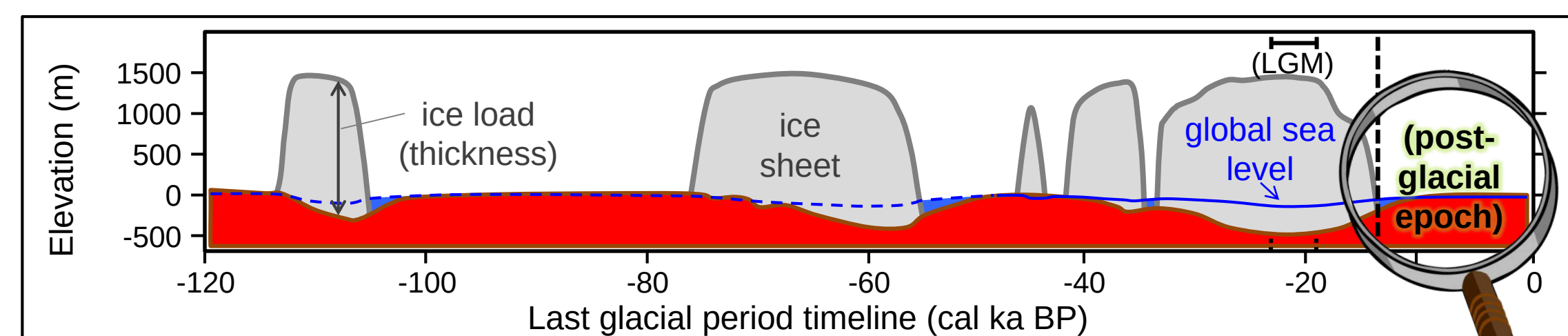
Marc Laurencelle^{(1)*}, René Lefebvre⁽¹⁾, John Molson⁽²⁾, Michel Parent⁽³⁾

1. INTRODUCTION AND OBJECTIVES

This study aims to better understand changes in regional aquifer dynamics that followed the Champlain Sea marine incursion, $\approx 13\,000$ years ago.

The main objectives are to:

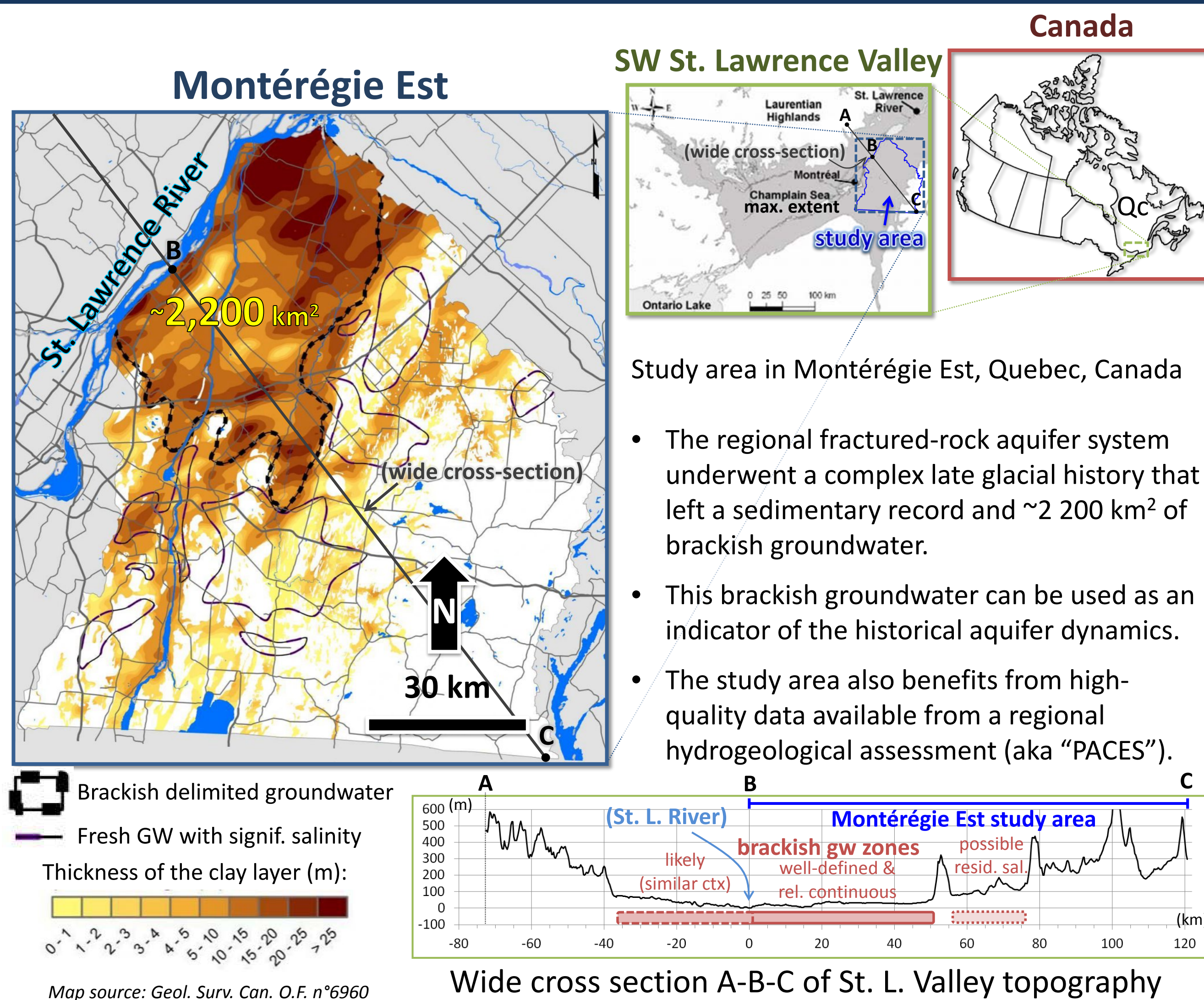
1. reconstruct the evolution of groundwater salinity and dynamics following deglaciation, using physically-based numerical models;
2. identify the key palaeo-hydrogeologic processes involved;
3. explain the present-day state of the system, especially the persistence of brackish groundwater even at shallow depths;
4. improve our understanding of high-amplitude marine transgression-regression effects on groundwater systems in general.



Surface conditions during the last glacial cycle

(non-local example data for Waterloo, Ontario, Canada; adapted from Lemieux et al., 2008)

2. STUDY AREA & ITS INTRIGUING “BRACKISH AREA”



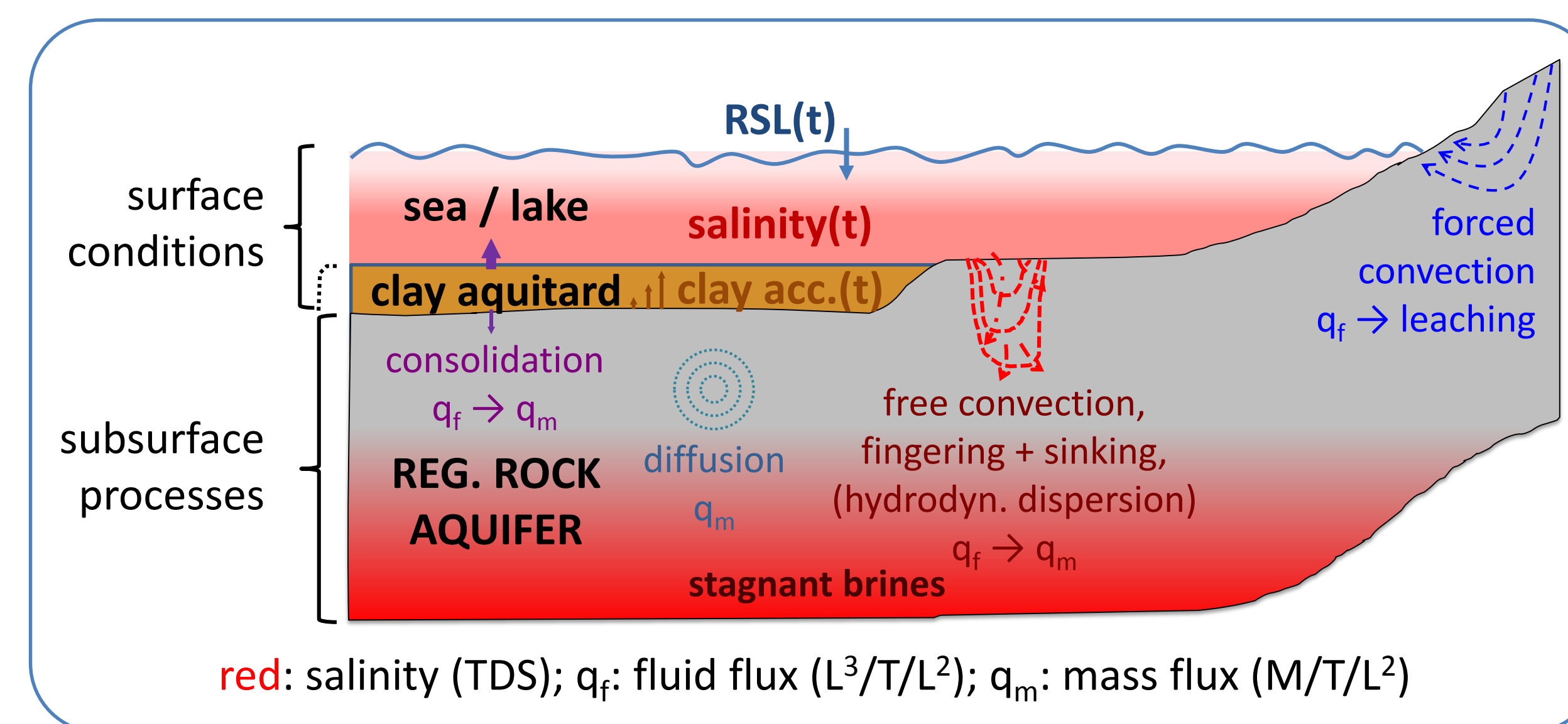
Study area in Montérégie Est, Quebec, Canada

- The regional fractured-rock aquifer system underwent a complex late glacial history that left a sedimentary record and $\sim 2\,200\text{ km}^2$ of brackish groundwater.
- This brackish groundwater can be used as an indicator of the historical aquifer dynamics.
- The study area also benefits from high-quality data available from a regional hydrogeological assessment (aka “PACES”).

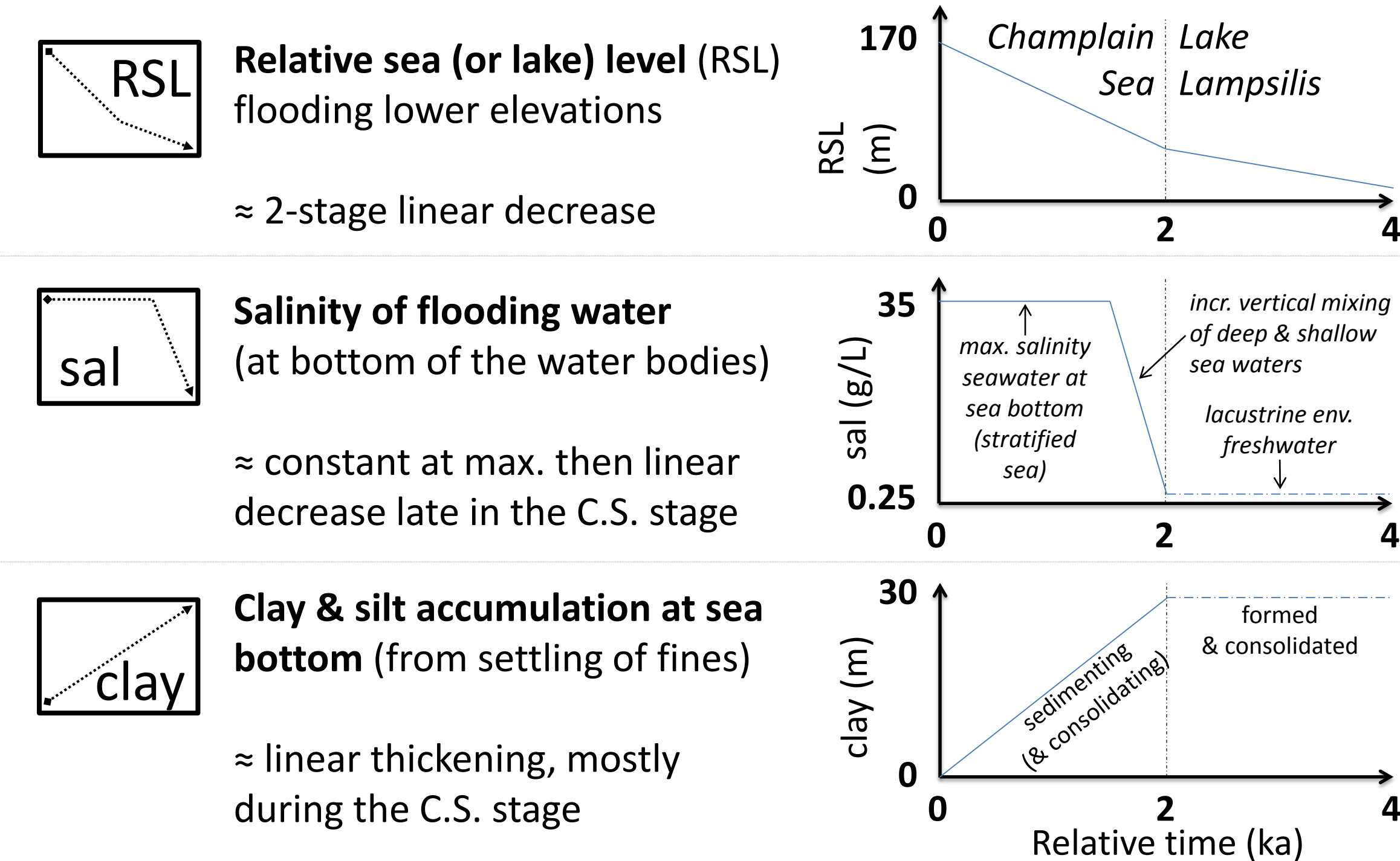
3. METHODS

Numerical modeling is required to represent this coupled flow & transport problem (water density depends on salinity), in a system with complex geometry (e.g. topography) with spatial and temporal variations of model parameters and boundary conditions.

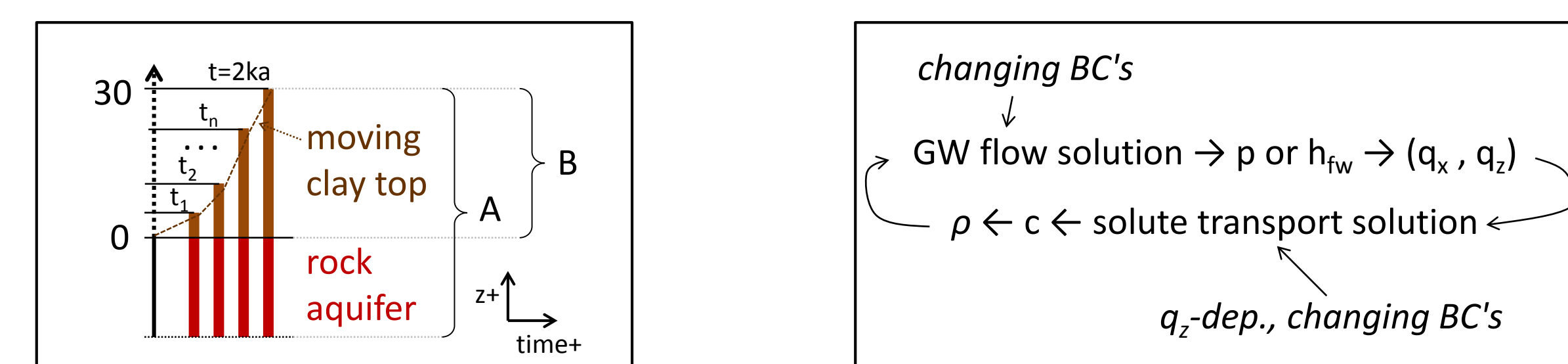
Conceptualisation of the palaeo-problem:



Conceptualization of palaeo-conditions (at model surface):



Numerical modeling approach:

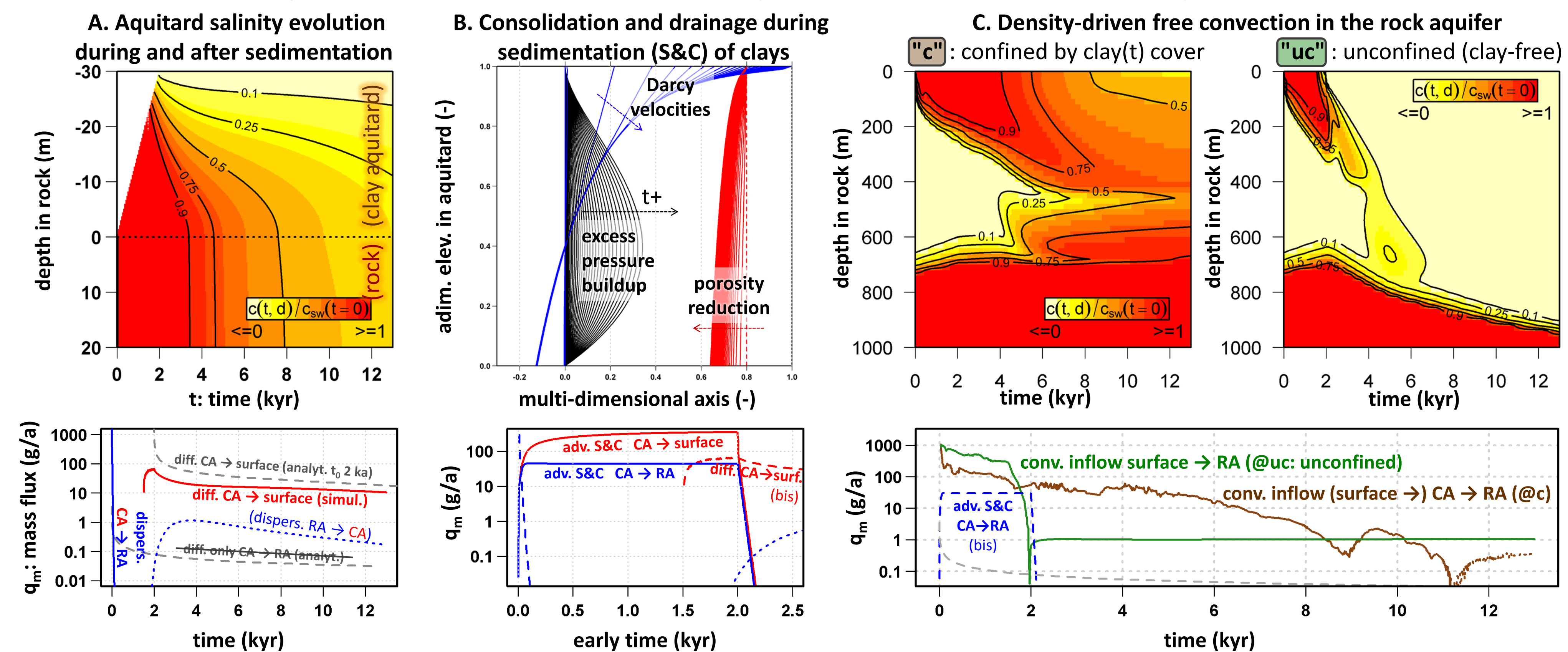


1Dz(t) model for: **A)** advective-dispersive salt transport in and below the forming aquitard; **B)** expulsion of saltwater from the forming aquitard due to clay accumulation & consolidation

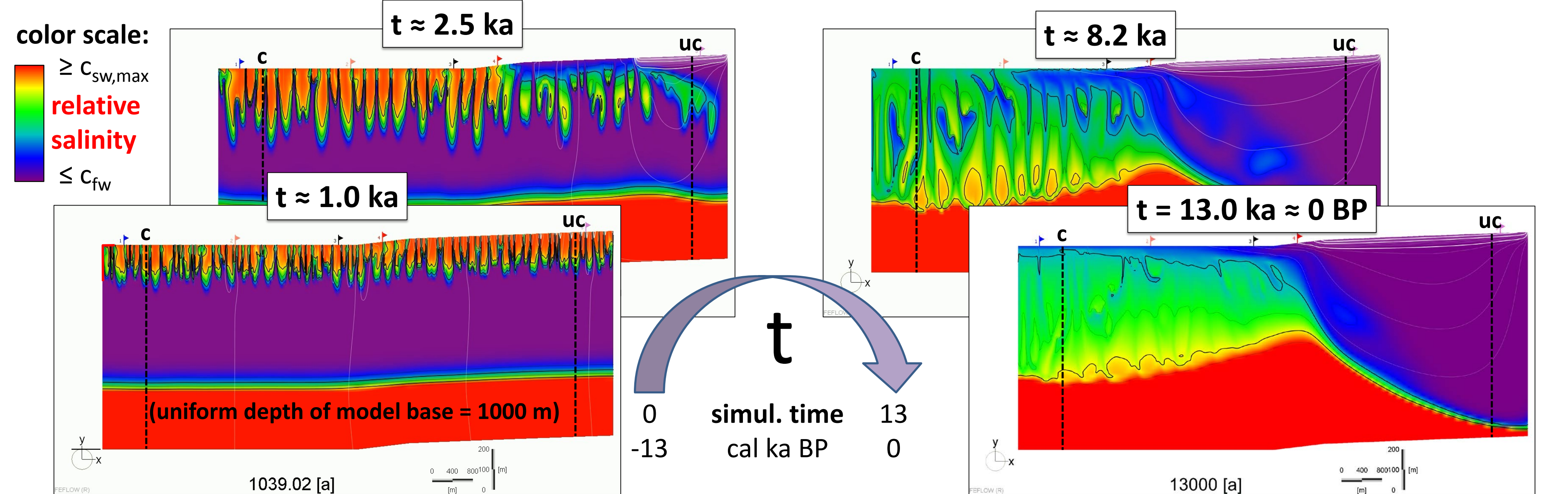
2Dxz(t) model flowchart for: **C)** variable density coupled flow & transport, with fully-transient conditions at model surface

4. RESULTS

i) Quantitative comparison of mass fluxes for different processes, alone (A, B, C) or coupled (A & C)



ii) A plausible reconstitution of the evolution of groundwater salinity and dynamics following deglaciation (A & C)



5. CONCLUSION

- Density-driven free convection dominates salt transport in the rock aquifer, even in clay-confined areas.
- Consolidation of clay generates advective mass fluxes that bring salt into the rock aquifer.
- Diffusive fluxes from the base of the clay aquitard to the rock aquifer are negligible compared to other fluxes.
- Diffusive fluxes from the aquitard to the overlying sea / lake / surface are the dominant transport process controlling the post-marine evolution of salinity in the aquitard and, hence, underneath.
- Density-driven saltwater fingers sink until they reach the brine “floor”; afterward, groundwater salinity is progressively homogenized by spreading and mixing.
- In higher areas not covered by clay, salty water leaching by fresh groundwater is substantial, whereas leaching is very limited under the aquitard, thus explaining the presence today of brackish groundwater in the aquifer.