



Semi-analytical model of brine leakage through an abandoned plugged well to determine the Area of Review for CO₂ geological storages

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► To cite this version:

Arnaud Réveillère, Jeremy Rohmer. Semi-analytical model of brine leakage through an abandoned plugged well to determine the Area of Review for CO₂ geological storages. EGU General Assembly 2012, Apr 2012, Vienne, Austria. hal-00658780

HAL Id: hal-00658780

<https://brgm.hal.science/hal-00658780>

Submitted on 18 Jun 2012

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A detailed geological cross-section or map. It features several distinct geological layers represented by different colors and patterns. Brown/orange wavy lines indicate folded rock strata. Blue areas represent specific geological formations or perhaps water bodies. Various labels are scattered throughout, such as "hsc", "hsa-b", "nso", "dsb", "ho-2", "cr-his", "da-his", "his", "dab", "Ga", "hb-2", "Gx". A prominent blue-shaded region covers the upper central part of the diagram. At the bottom left, there's a coordinate-like label "4 80 3740 46 -625 5".

**Semi-analytical model of brine leakage through
an abandoned plugged well to determine the
Area of Review for CO₂ geological storages**

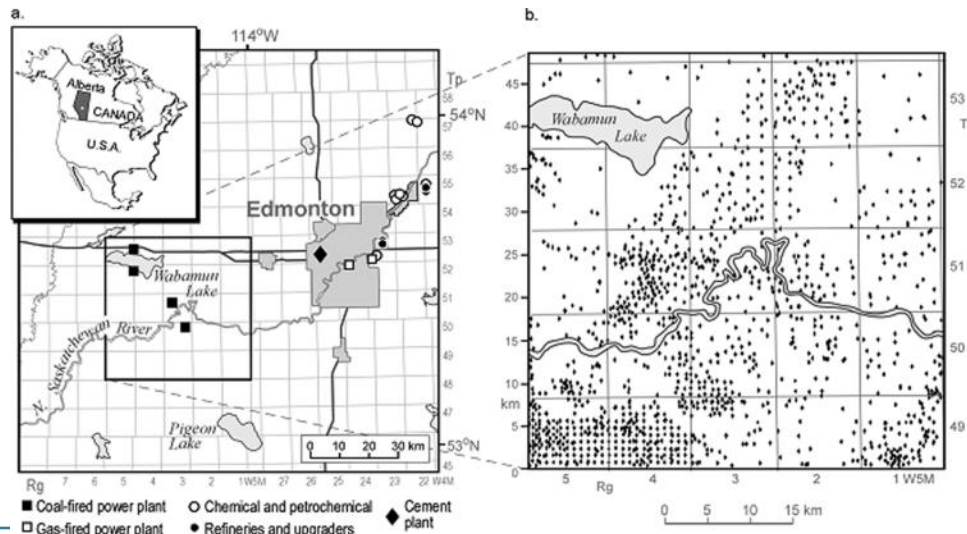
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Abandoned wells review – context overview



- > **Many CO₂ storage projects target deep saline aquifers located in sedimentary basins**
 - Possible historical oil & gas operations
 - Abandoned wells with sometimes unknown plugging records
- > **By leaking through abandoned (plugged) wells, the saline brine risks to leak into overlying fresh water aquifers**
 - wells in the area where this is possible should be reviewed (“Area of review”)
 - This model enables to prioritize the areas to review supposing minimum plug parameters



Example in Alberta, Canada: 508 wells in a 30km x 30 km area.
from Bachu and Celia, 2009

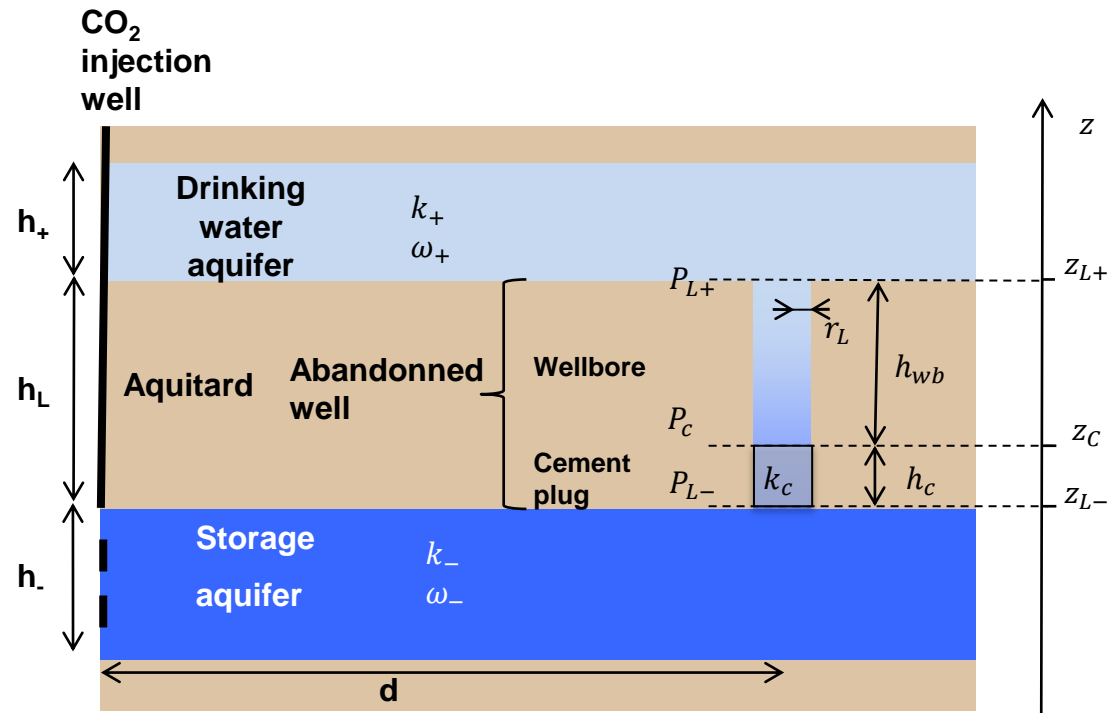
Schematic layout of the model



> 1 active injection well

> 1 passive abandoned well, or « Leak »

- $z_c = z_{L-}$: wellbore only
- $z_c = z_{L+}$: porous column only
- $z_{L-} < z_c < z_{L+}$: plug & wellbore

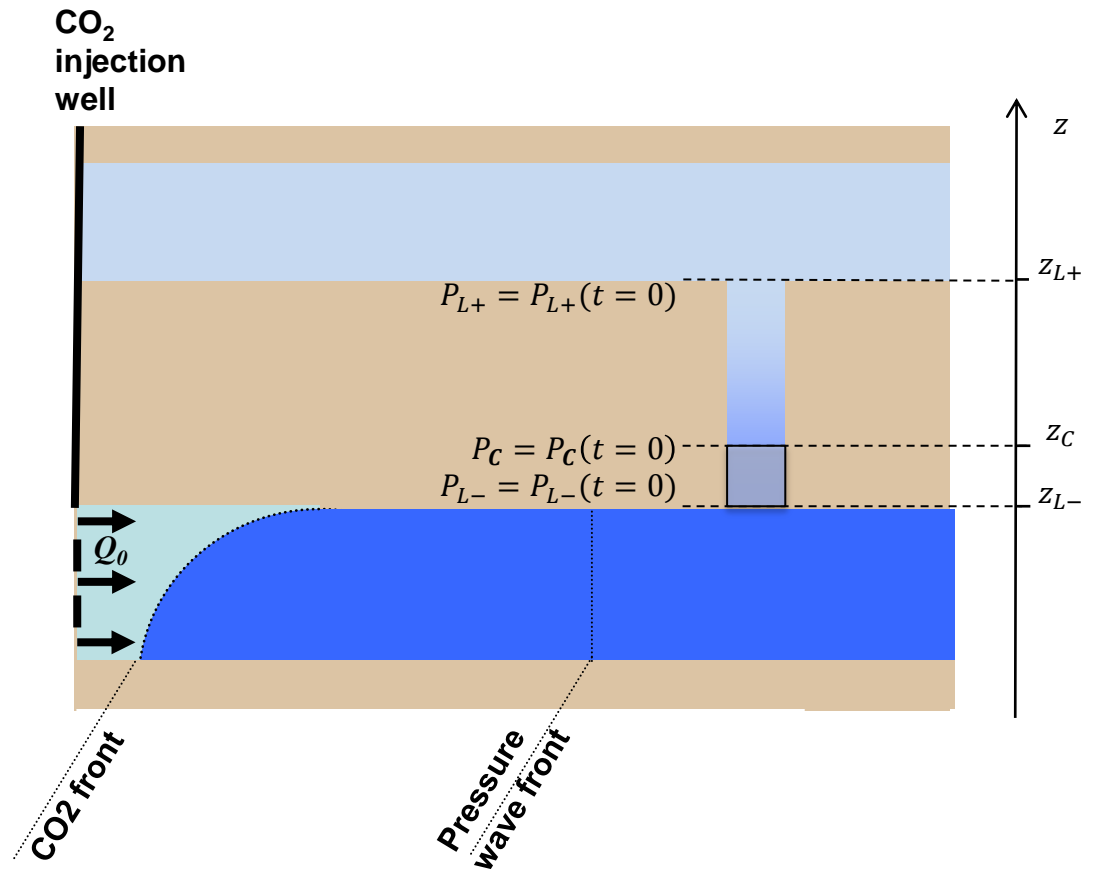


- Drinking water
- Storage aq. brine
- Wellbore brine (vertical salinity gradient)

Beginning of CO₂ injection



- > Constant CO₂ injection flow rate starts (Q_0)

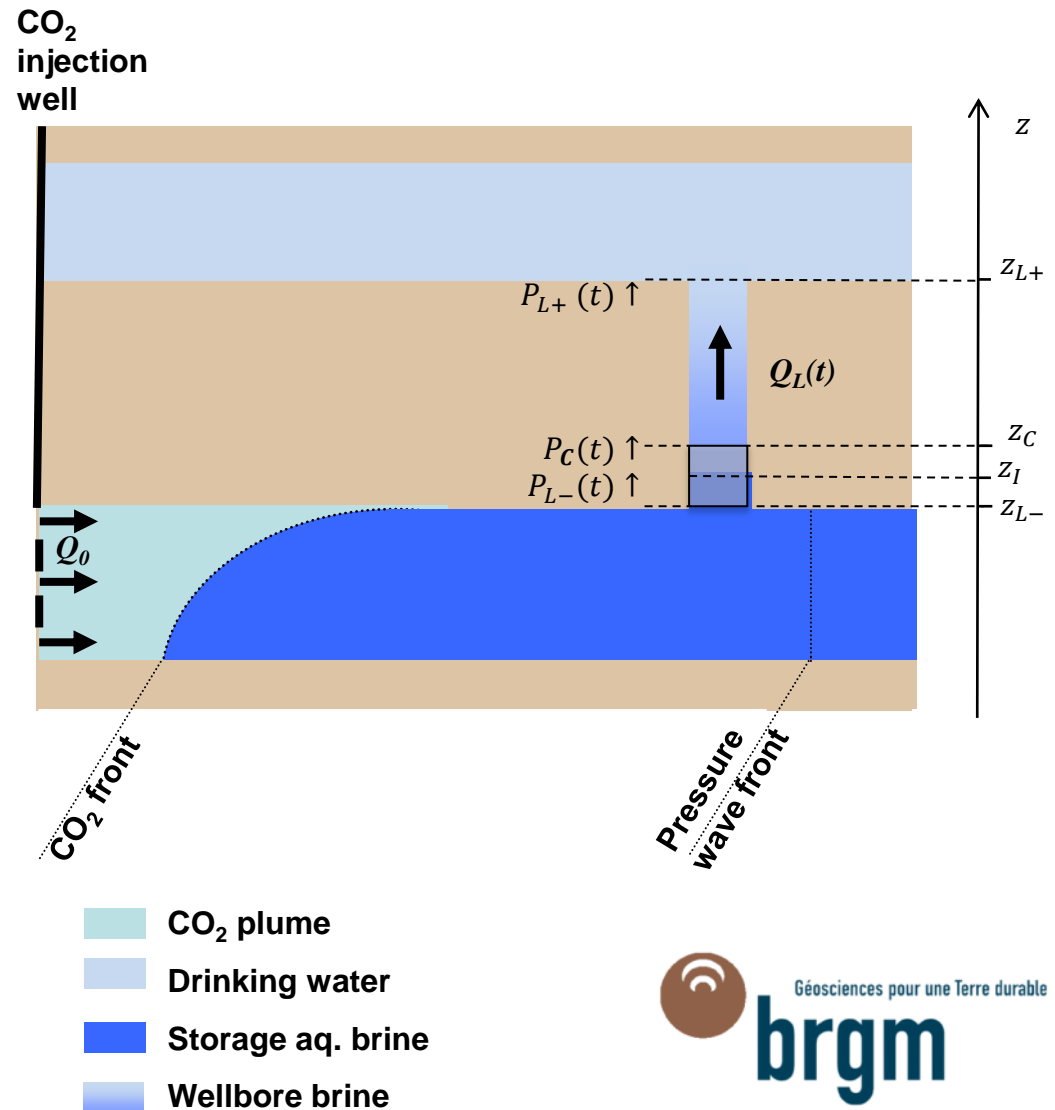


- CO₂ plume
- Drinking water
- Storage aq. brine
- Wellbore brine

Brine leakage during CO₂ injection



- > Dense storage aquifer brine starts filling the leak up to z_l
- > The « wellbore brine » is pushed up
- > Pressure increases in the abandoned well

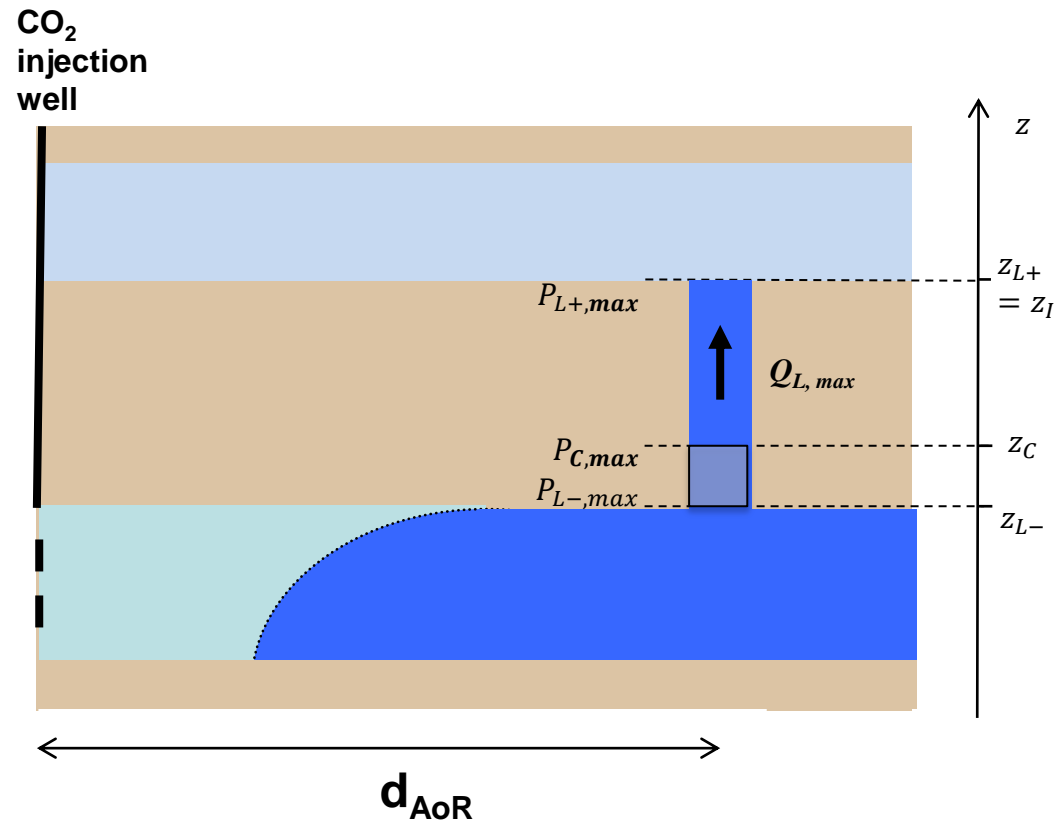


End of the CO₂ injection & « AoR »



> « Area of review » d_{AoR} :

Area where the pressure changes due to the injection can drive the reservoir brine up to a shallower aquifer of interest



- CO₂ plume
- Drinking water
- Storage aq. brine

Equations of the model



- > Static pressure equation in the abandoned well**
- > Pressure under the leak in the storage aquifer**
- > Pressure over the leak in the overlying aquifer**
- > Mass conservation**
- > Darcy flow in the cement plug**
- > Semi-analytical resolution**

Static pressure equation in the abandonned well



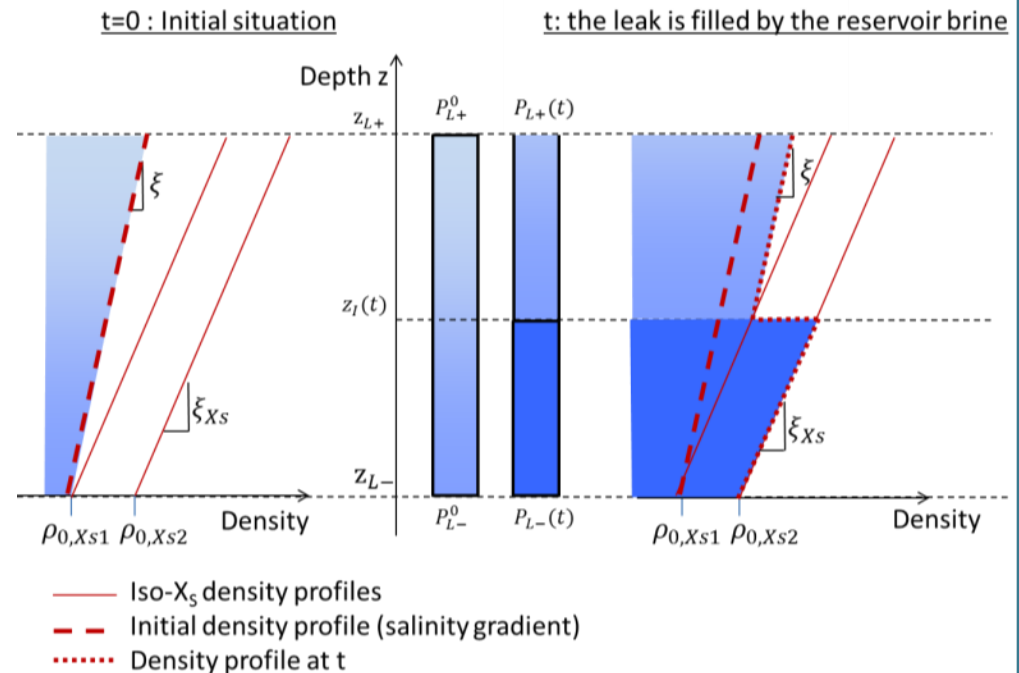
> Well bore pressure gradient

$$\nabla P = \nabla P_{grav} + \nabla P_{fric} + \nabla P_{acc}$$

- « frictional and inertial pressure gradients contributing typically a few percent or less.” (Pruess, 2006, for geothermal wells)

- $\rightarrow \nabla P = \nabla P_{grav}$

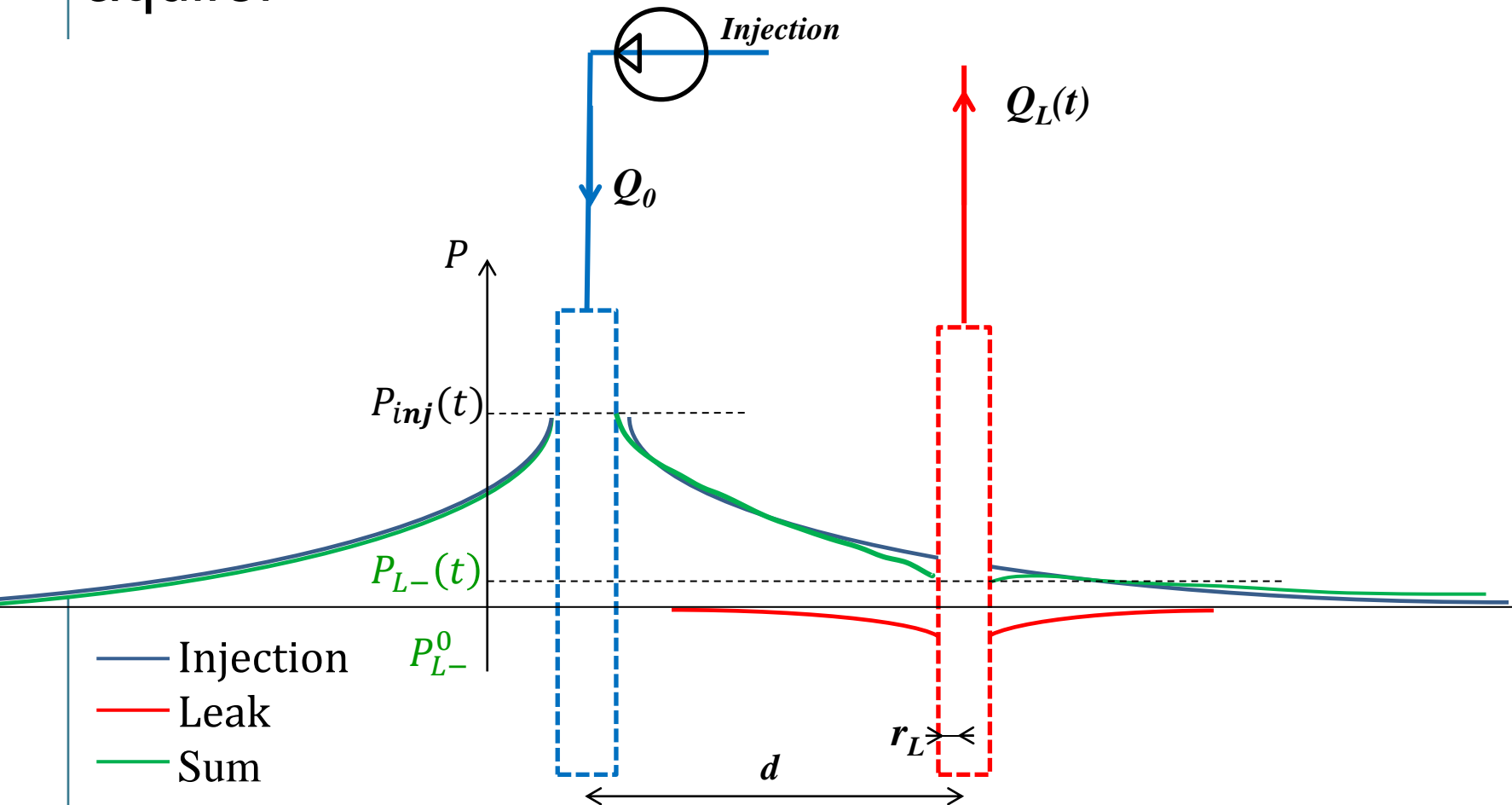
> Thermal equilibrium (Oldenburg & Rinaldi 2011)



$$P_{L-}^{static} - P_C^{static} = \Delta P_{cp}^0 + \Delta P_{cp}^1(z_I)$$

$$P_C^{static} - P_{L+}^{static} = \Delta P_{wb}^0 + \Delta P_{wb}^1(z_I)$$

Pressure under the leak in the storage aquifer



- Injection
- Leak
- Sum

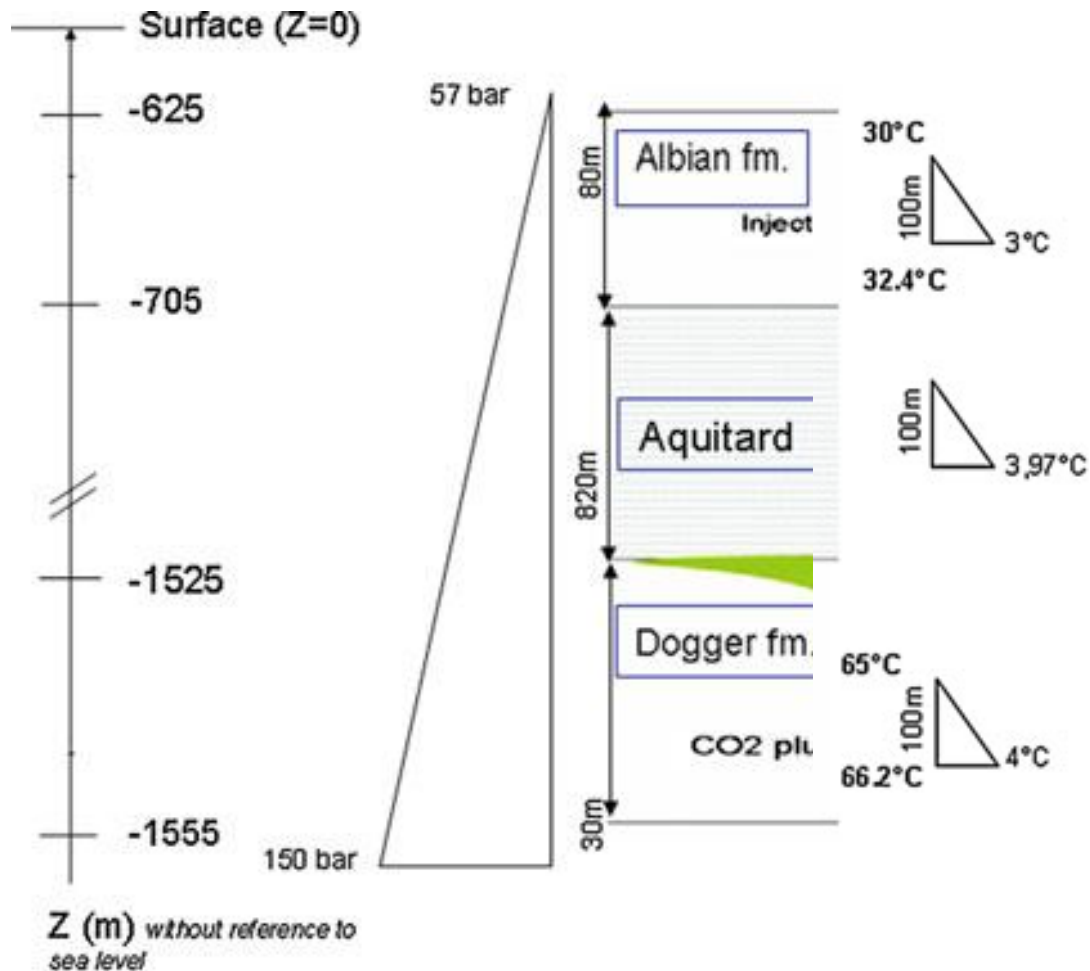
$$P_{L-}(t) - P_{L-}^0 = \frac{\mu_-}{4\pi k_- h_-} \left[Q_0 E_1 \left(\frac{d^2 S_-}{4T_- t} \right) - \int_0^t \frac{dQ_L}{dt'} E_1 \left(\frac{r_L^2 S_-}{4T_- (t - t')} \right) dt' \right]$$



Géosciences pour une Terre durable

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Application to the « PICOREF » sector, Paris basin

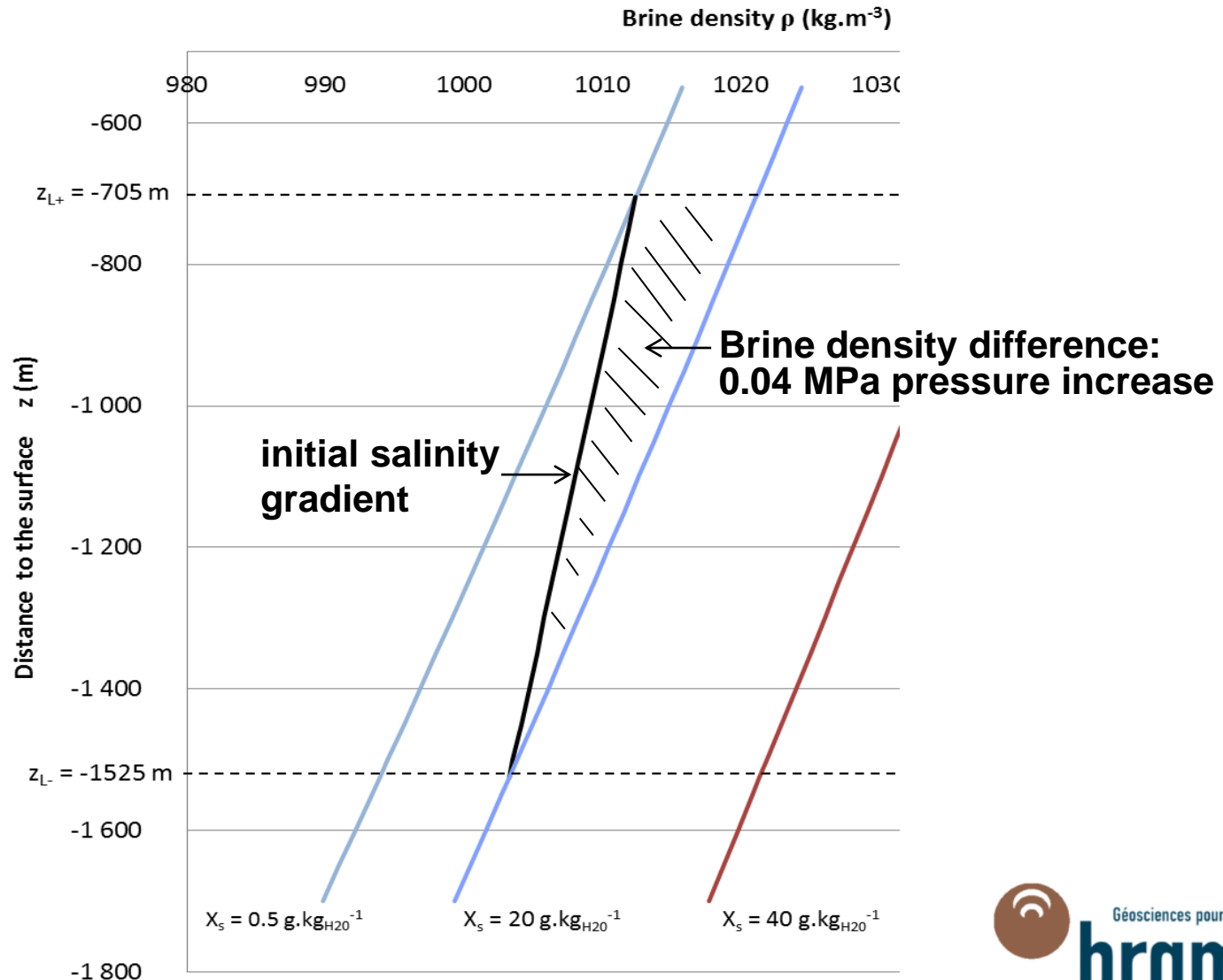


Hydrostatic pressure

hermal gradient

P, T, X_S correspond to the Paris basin context as presented in Humez et al. (2011).

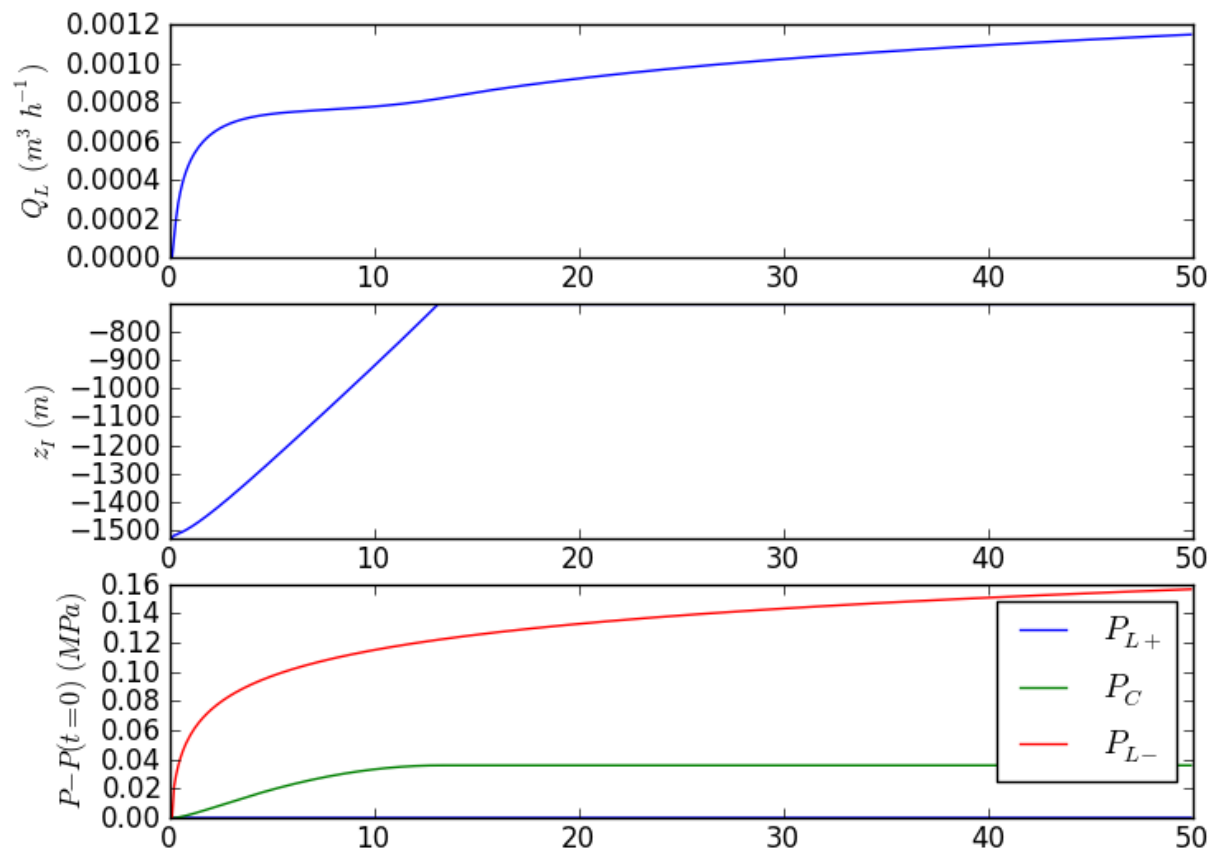
Brine density profile



Example of brine leakage



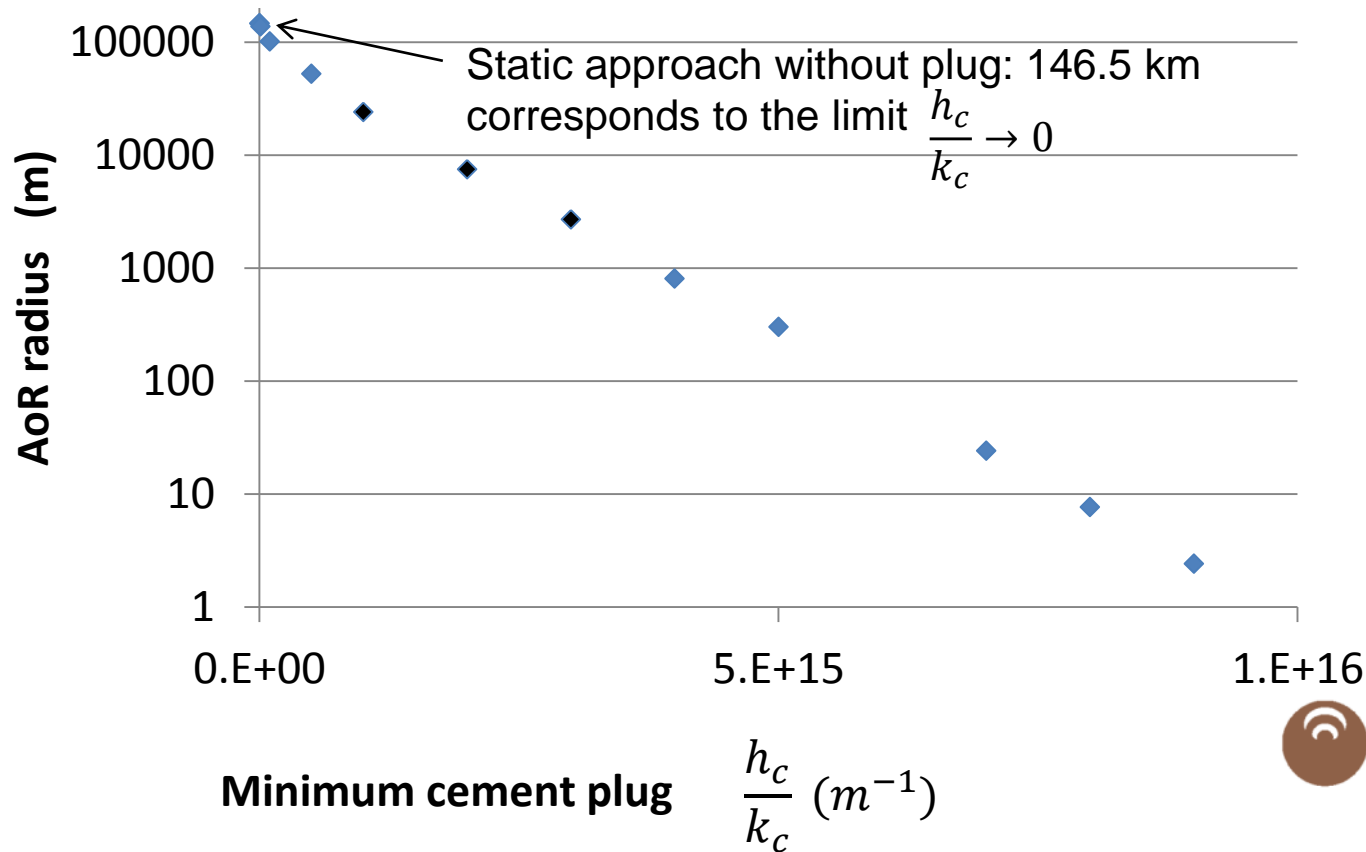
- CO₂ injection scenario: 1 Mt/y for 50 years
- D=6.7 km from the injection to the abandoned well
- Cement plug: 10 m high, weak permability of 10^{-13} m^2



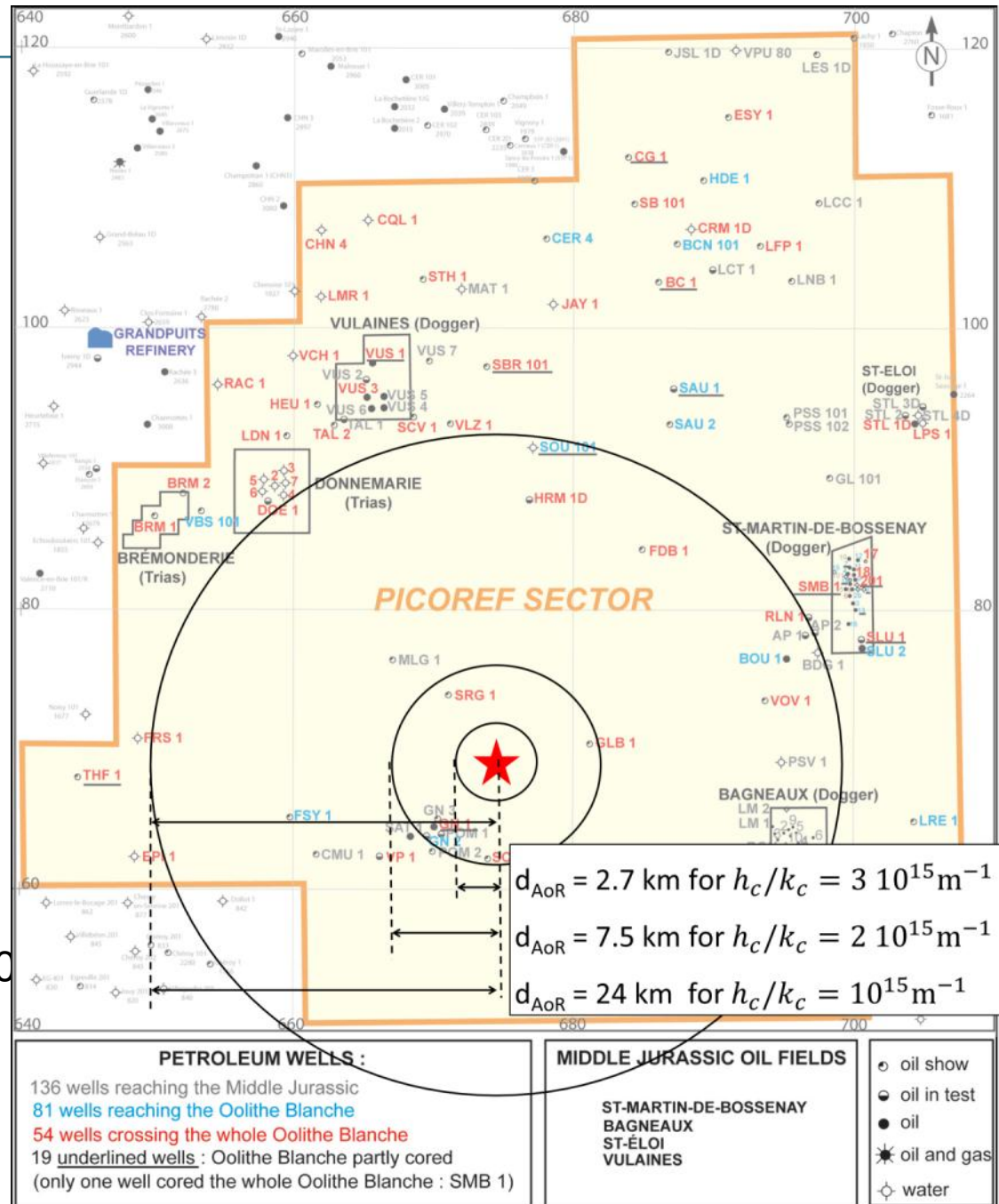
Area to review for a minimum cement plug height on permeability ratio



> CO₂ injection scenario: 1 Mt/y for 50 years



Prioritization of the wells to review



Adapted from Delmas et al., 2010



> Conclusions

- The model describes the leakage of brine through the leak. Compared to the state of the art (Nordbotten, Celia and co-authors, 2004-2009), it adds the possibility of accounting for density change within the leak due to the incoming of dense brine
- It shares the advantages (immediate computation) and drawbacks (homogeneous layers) of semi-analytical models
- Compared to a static approach (Nicot et al., 2009), this dynamic model enables less conservative estimation of the “Area of Review”, by including effects of cement plugs, of brine density differences and of leakage-induced pressure effects

> Next steps

- Inclusion of the CO₂ leakage
- Monte-Carlo analyses

> **Thanks!**

> **Acknowledgements**

- This work has been supported by the BRGM's Research project *CO₂ risks Management* integrated in the Research project CSCR03.

References



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