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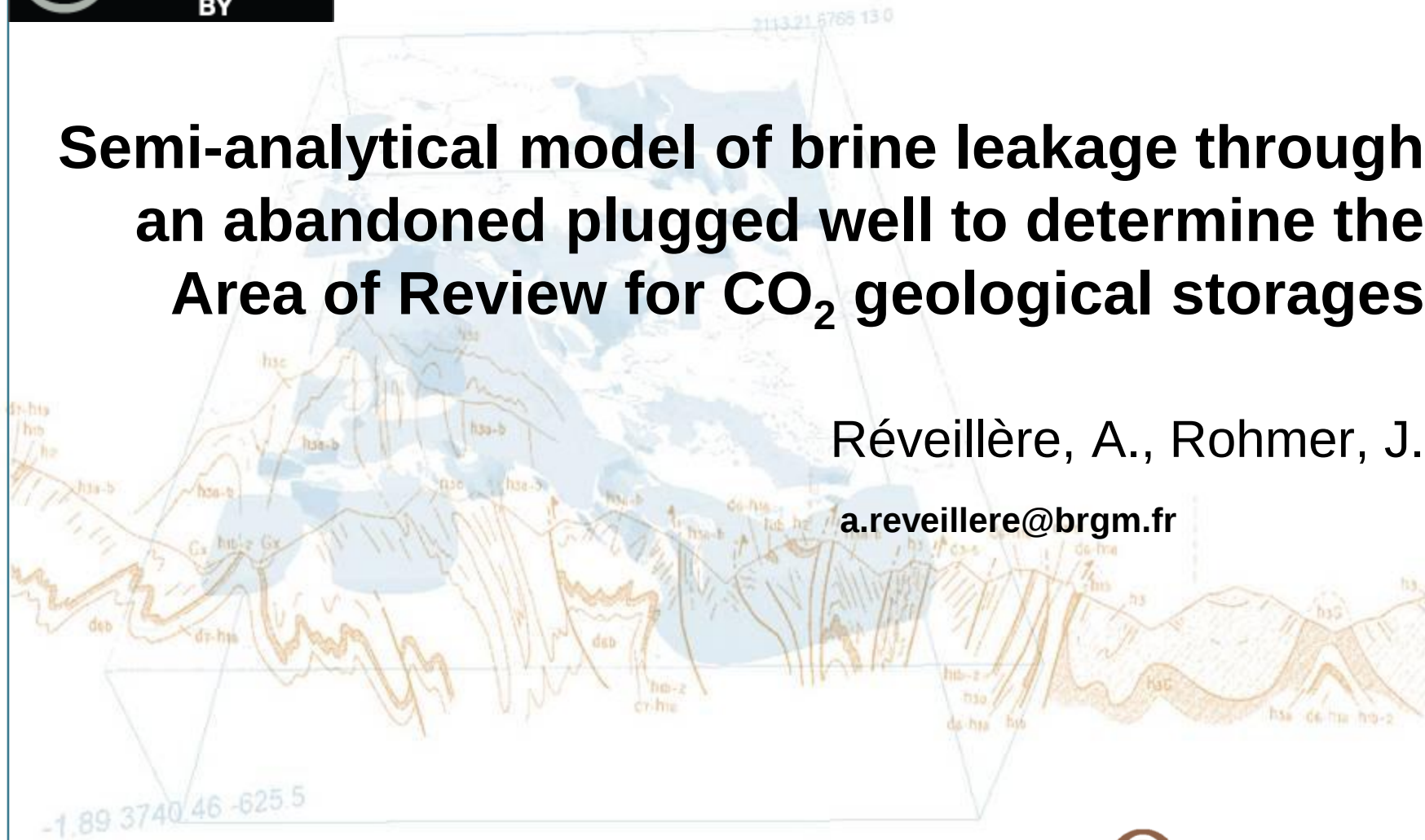
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Semi-analytical model of brine leakage through an abandoned plugged well to determine the Area of Review for CO₂ geological storages

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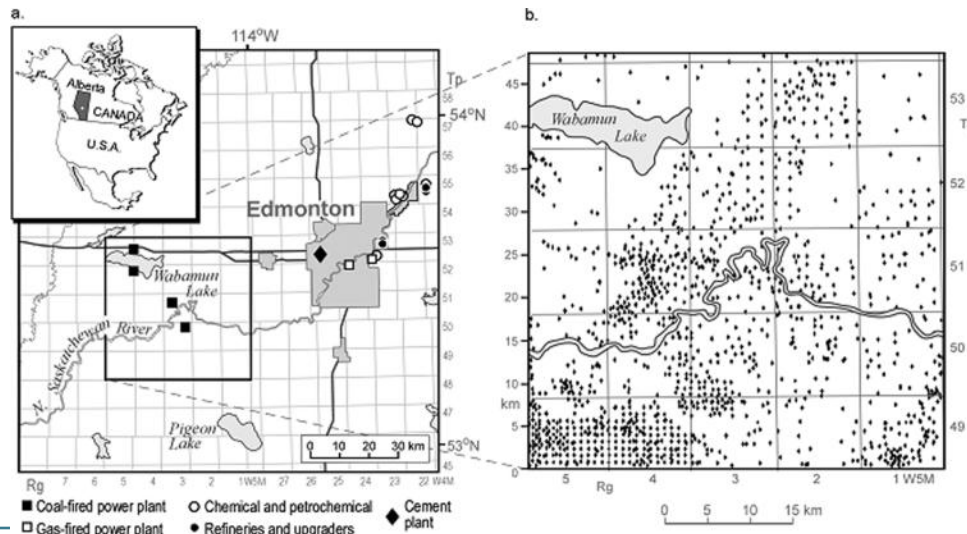
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Abandoned wells review – context overview



- **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

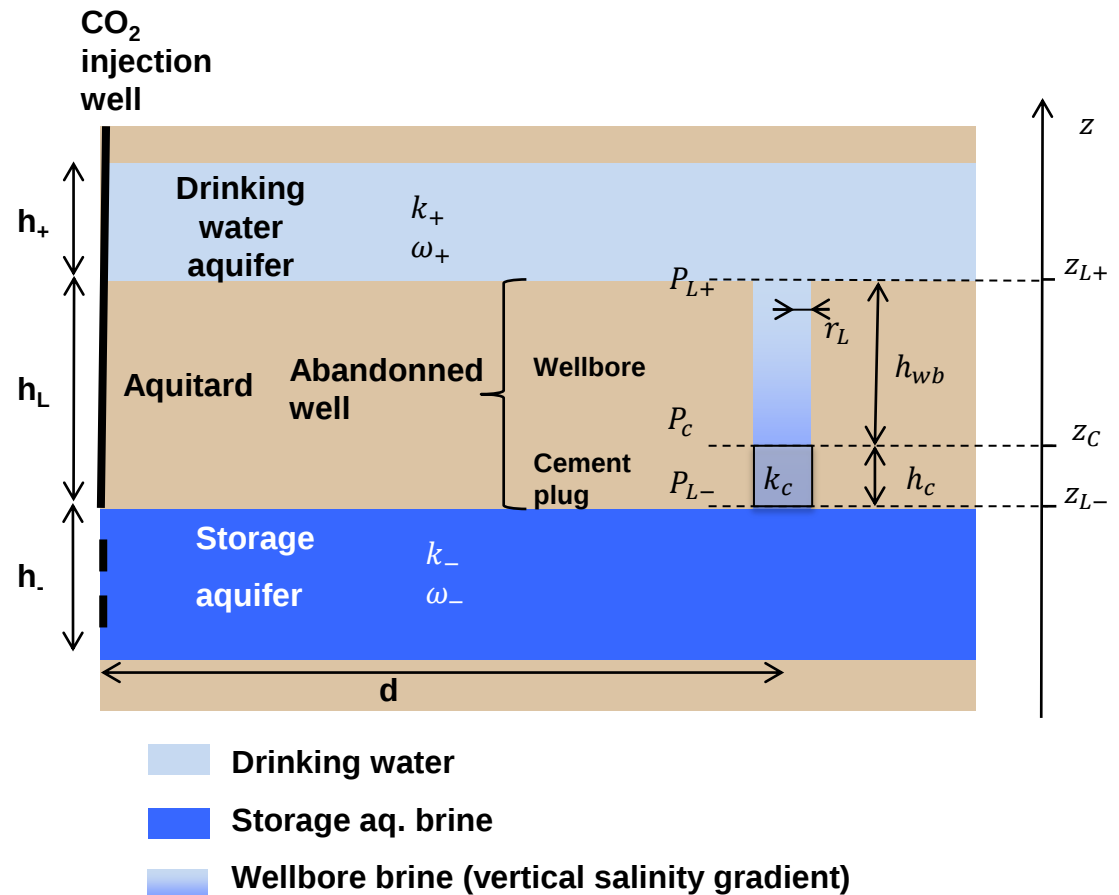
Schematic layout of the model



> 1 active injection well

> 1 passive abandoned well, or « Leak »

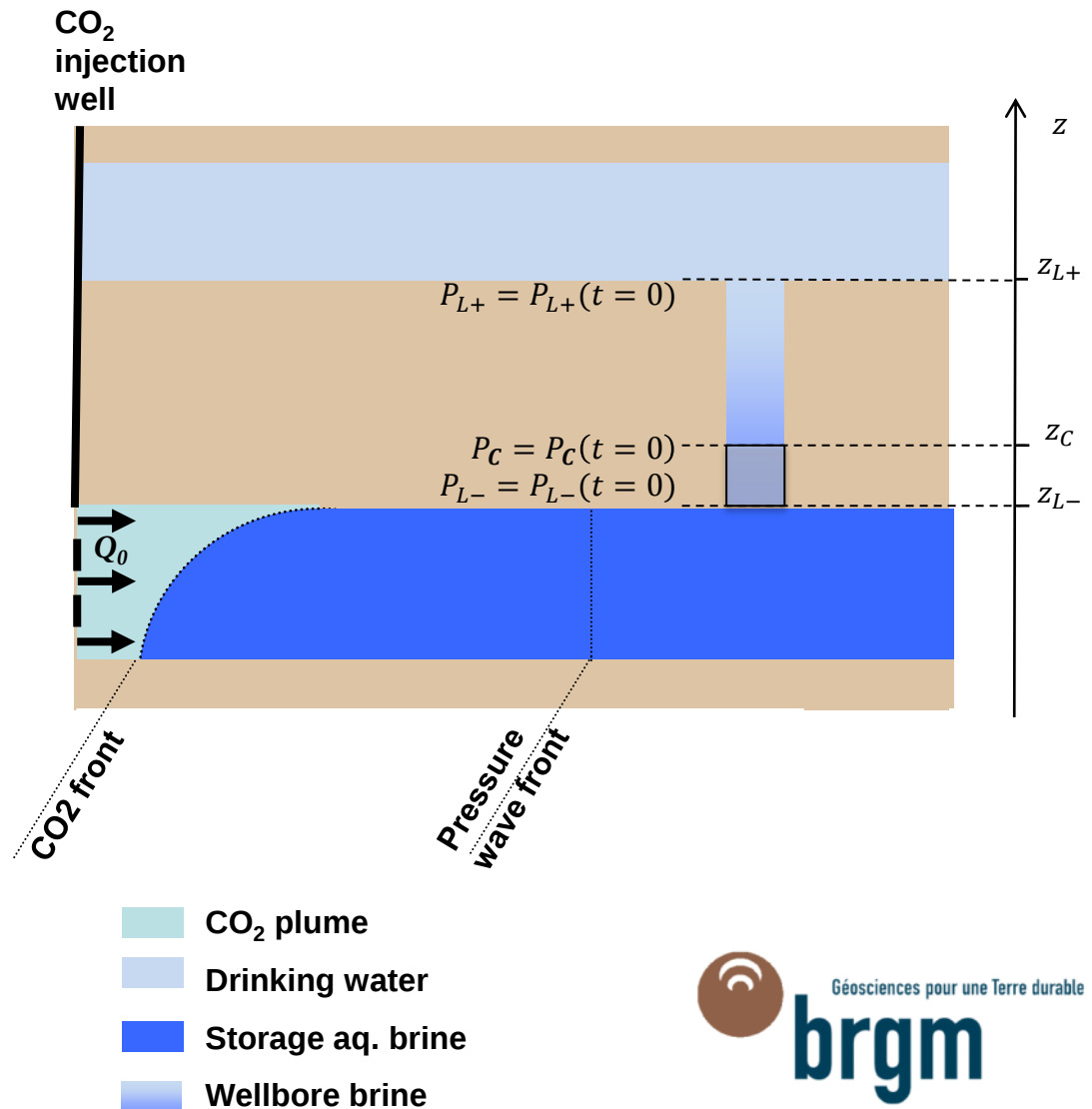
- $z_c = z_{L-}$: wellbore only
- $z_c = z_{L+}$: porous column only
- $z_{L-} < z_c < z_{L+}$: plug & wellbore



Beginning of CO₂ injection



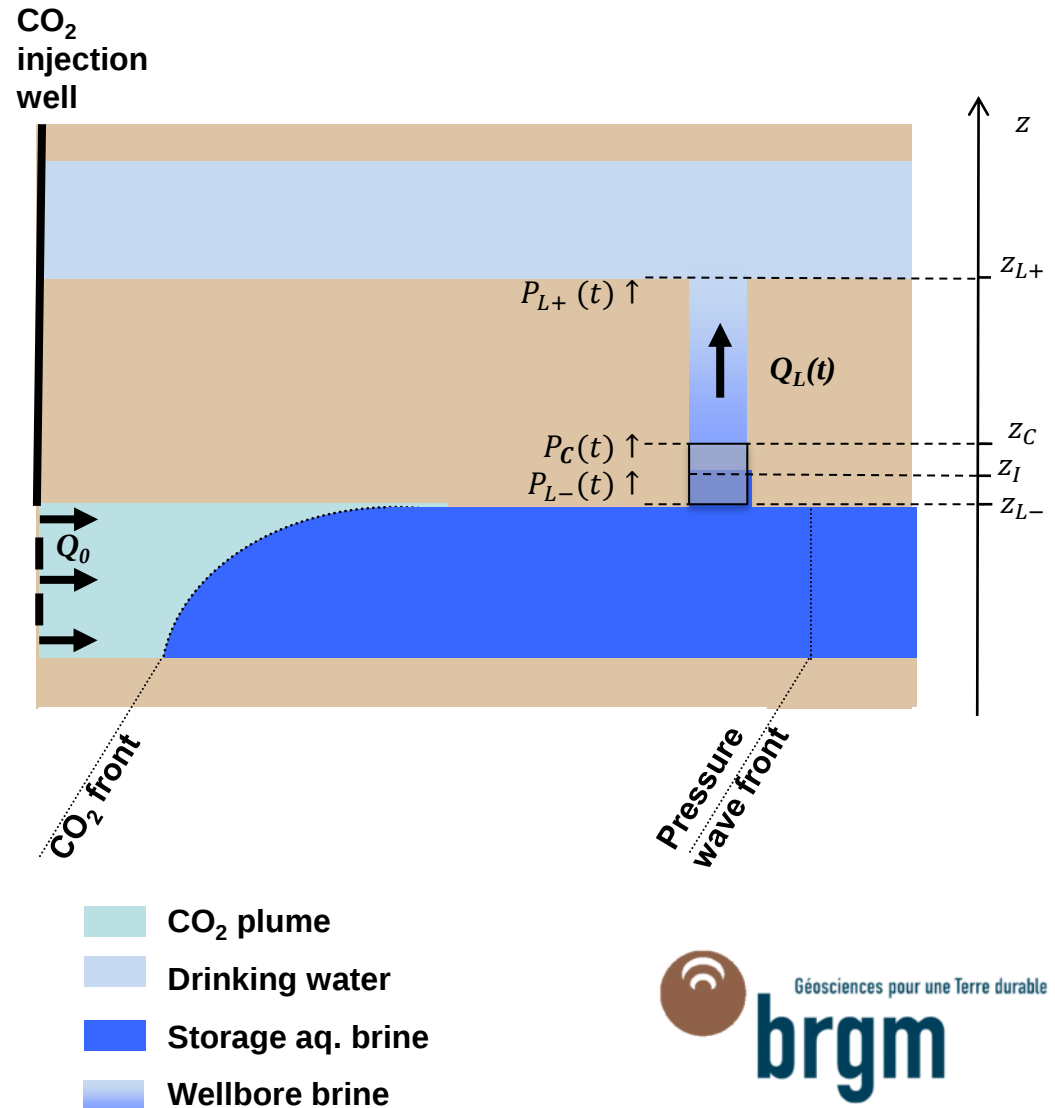
- > Constant CO₂ injection flow rate starts (Q_0)



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

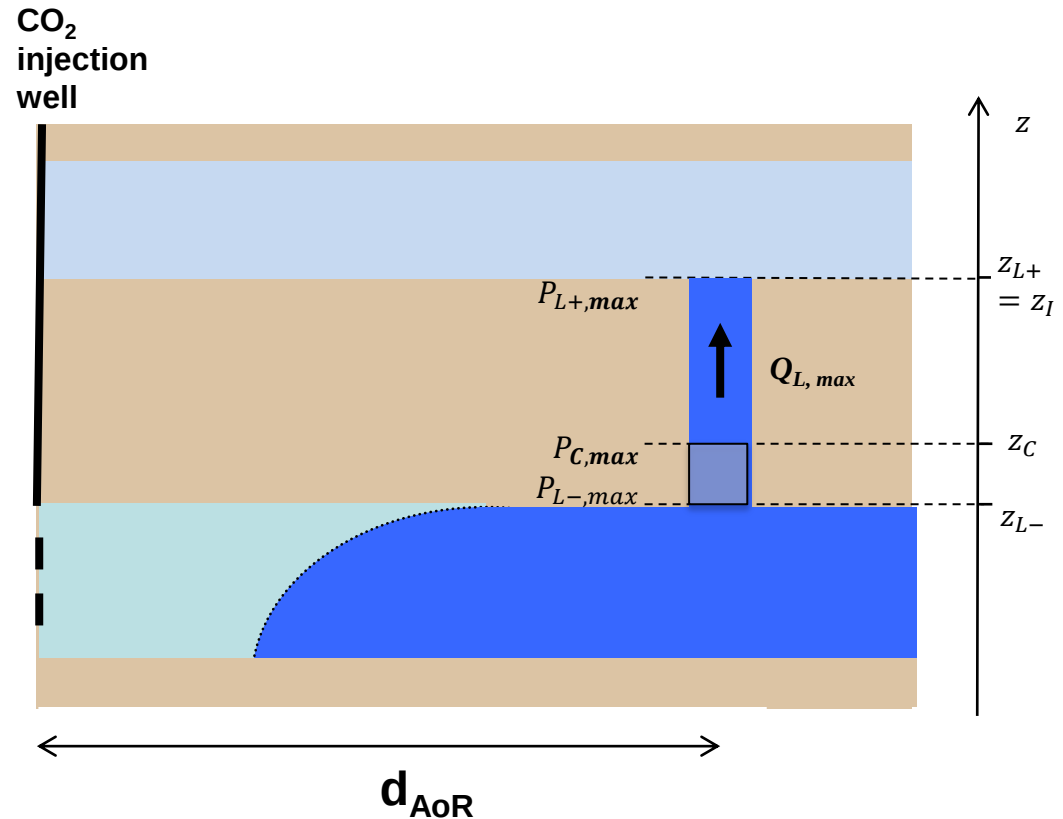


End of the CO₂ injection & « AoR »



> « 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



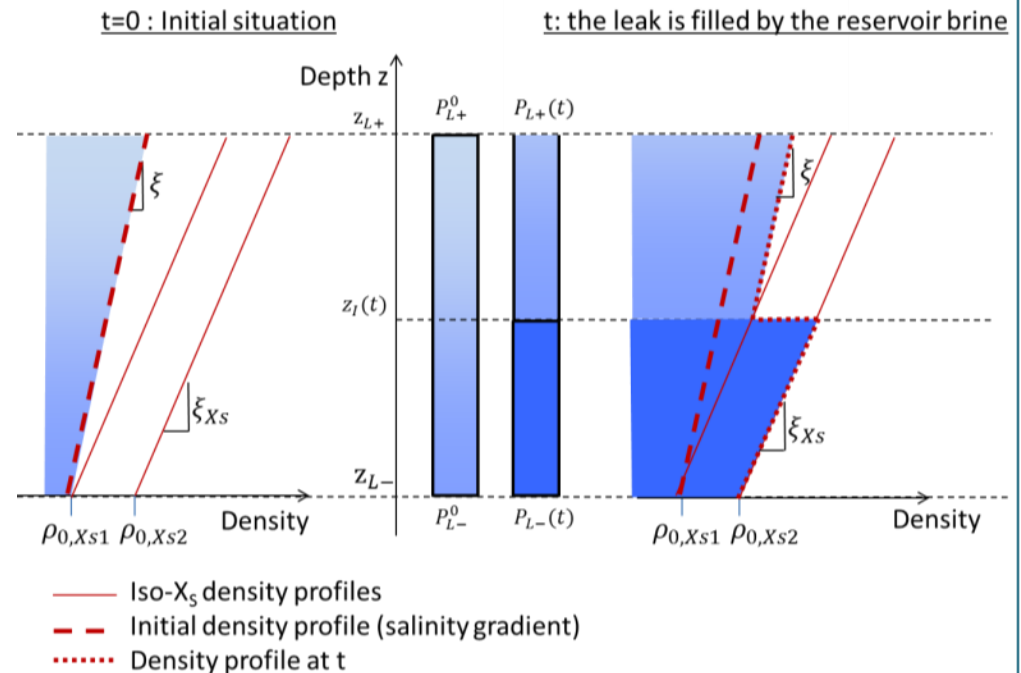
> Well bore pressure gradient

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

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

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

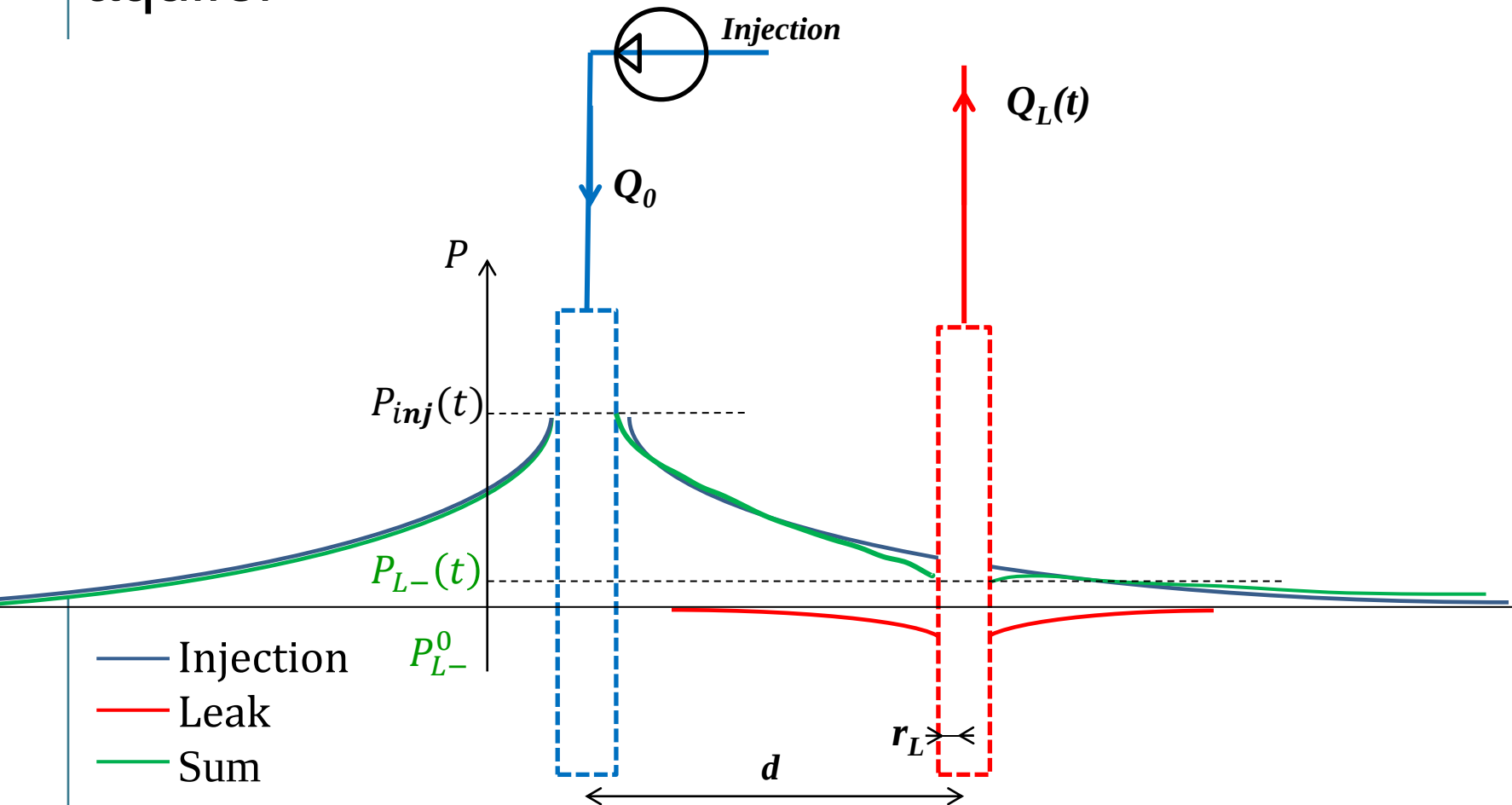
> Thermal equilibrium (Oldenburg & Rinaldi 2011)



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

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

Pressure under the leak in the storage aquifer



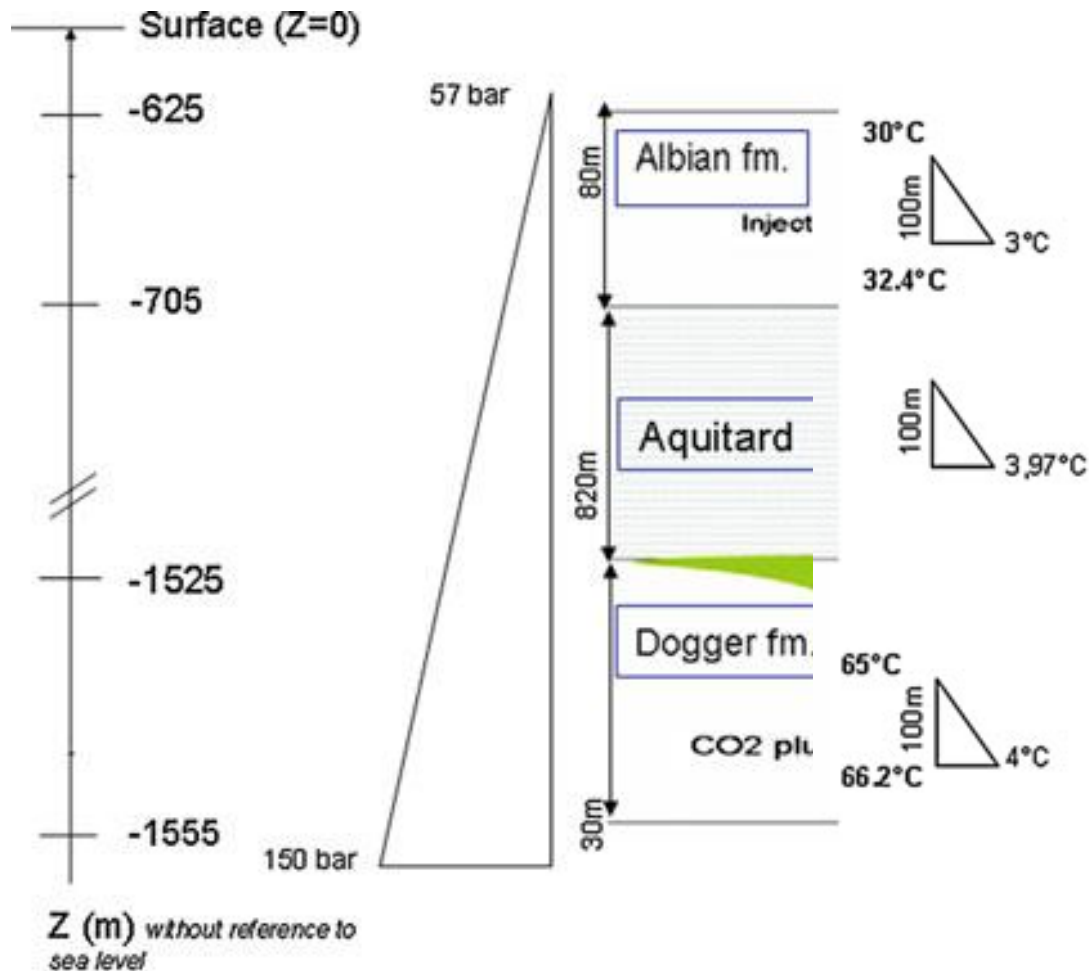
$$P_{L-}(t) - P_{L-}^0 = \frac{\mu_-}{4\pi k_- h_-} \left[Q_0 E_1 \left(\frac{d^2 S_-}{4T_- t} \right) - \int_0^t \frac{dQ_L}{dt'} E_1 \left(\frac{r_L^2 S_-}{4T_- (t - t')} \right) dt' \right]$$



Géosciences pour une Terre durable

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Application to the « PICOREF » sector, Paris basin

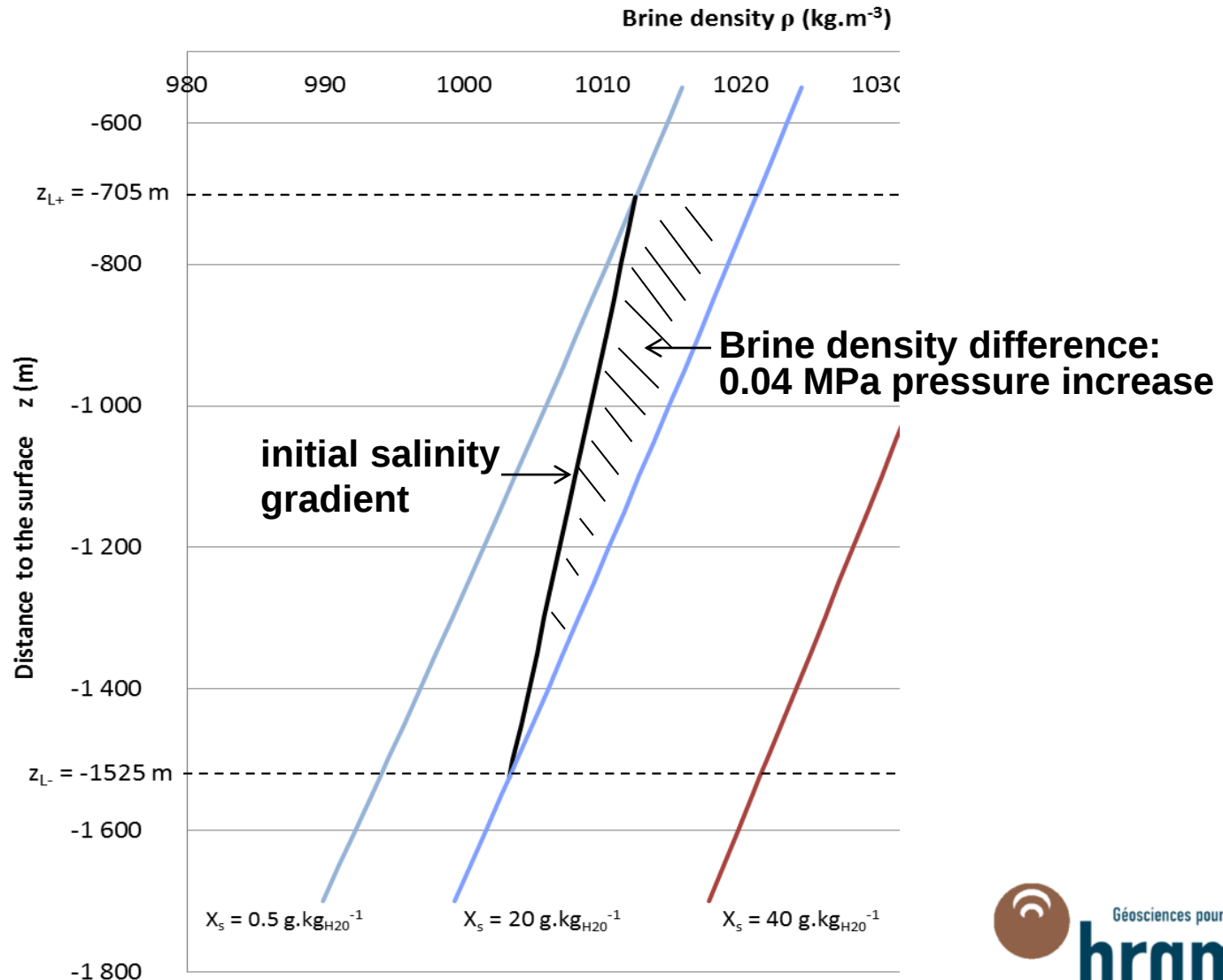


P, T, X_S correspond to the Paris basin context as presented in Humez et al. (2011).

Hydrostatic pressure

hermal gradient

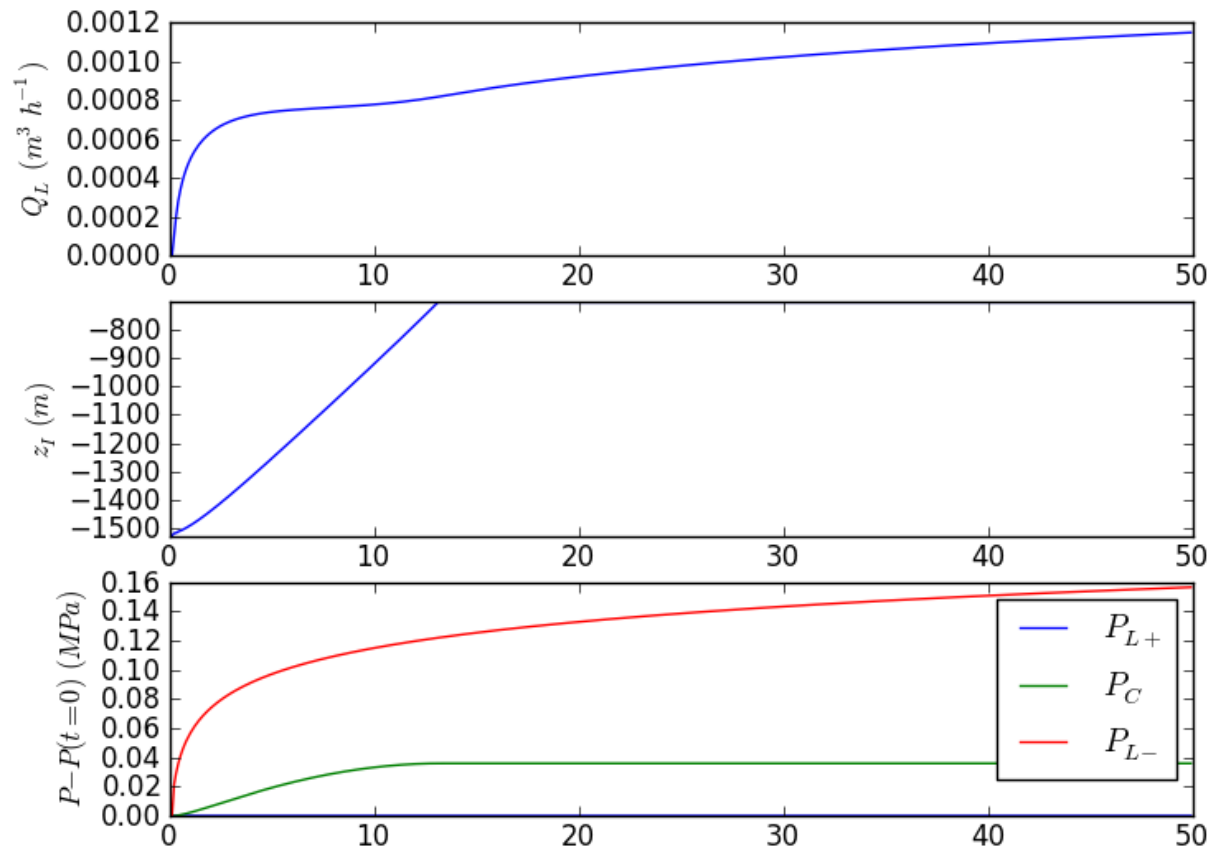
Brine density profile



Example of brine leakage



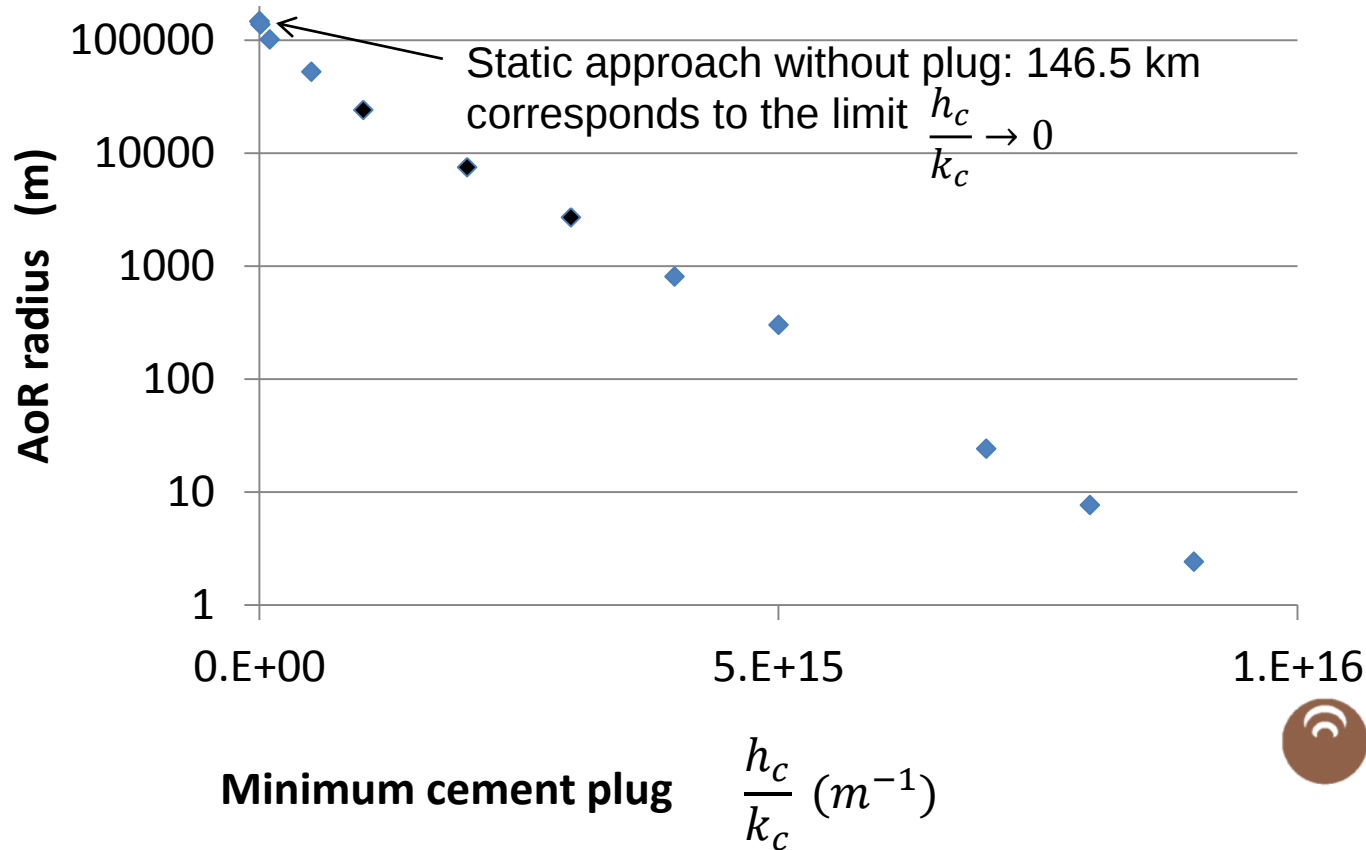
- CO₂ injection scenario: 1 Mt/y for 50 years
- D=6.7 km from the injection to the abandoned well
- Cement plug: 10 m high, weak permability of $10^{-13} m^2$



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



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



PETROLEUM WELLS :

136 wells reaching the Middle Jurassic
81 wells reaching the Oolithe Blanche
54 wells crossing the whole Oolithe Blanche
 19 underlined wells : Oolithe Blanche partly cored
 (only one well cored the whole Oolithe Blanche : SMB 1)

MIDDLE JURASSIC OIL FIELDS

ST-MARTIN-DE-BOSSENAY
 BAGNEAUX
 ST-ÉLOI
 VULAINES

• oil show
 • oil in test
 • oil
 • oil and gas
 ◊ water

> 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**

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