Coupling basin and reservoir simulators for an improved CO_2 injection flow model

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Introduction

This study is part of the ULTimateCO2 FP7 European project which aims to significantly enhance our knowledge of specific processes that may affect the long-term fate of geologically stored CO_2.

The long-term fate of stored CO_2 in a saline aquifer is directly influenced by geological characteristics (such as structural pattern, sedimentary architecture or petro-physical properties) and also by groundwater composition and flow. In order to assess the long-term fate of injected CO_2, 3D numerical reservoir models are built taking into account the natural spatial variability of facies and associated petrophysical properties. They are used to simulate natural fluxes and their modifications due to the injection of supercritical CO_2. Usually, the numerical flow model is initialized assuming a hydrostatic equilibrium. This type of initialisation does not take into account regional groundwater flow nor singularities in the pressure field that may ensue from the geological history.

The goal of this work is to model the present basin-scale groundwater flow of the Paris basin with a basin modelling approach and to use it to initialise a reservoir model for CO_2 injection. Basin models simulate the history of sedimentary basins through time coupling geological events such as deposition, erosion, compaction, structural deformation and subsurface flow simulation. It computes pressure, temperature and salinity fields over the basin history. The resulting present-day state of the basin model is then used as initial state of the reservoir numerical model. The latter is used to simulate the injection of CO_2 and its long-term effects on the pressure field for instance. The coupling between basin and reservoir simulators should help:

- to generate a more accurate initial state before the CO_2 injection simulation and
- to understand the influence of the pressure pulse induced by the CO_2 injection on brine displacement and possible change of hydrodynamics regime.

Geological model

The Paris basin is a 600 km-wide intracratonic sedimentary basin located in the North of France (Figure 1 - left). It is composed of a pile of Triassic to Tertiary sediments reaching a maximum thickness of 3 km in the central part of the basin. It is bounded by four blocks of outcropping Hercynian basement: The Ardennes in the northeast, the Vosges in the East, the Massif Central in the south and the Armorican massif in the west. It is open to the North towards the Belgium and the London Basins.

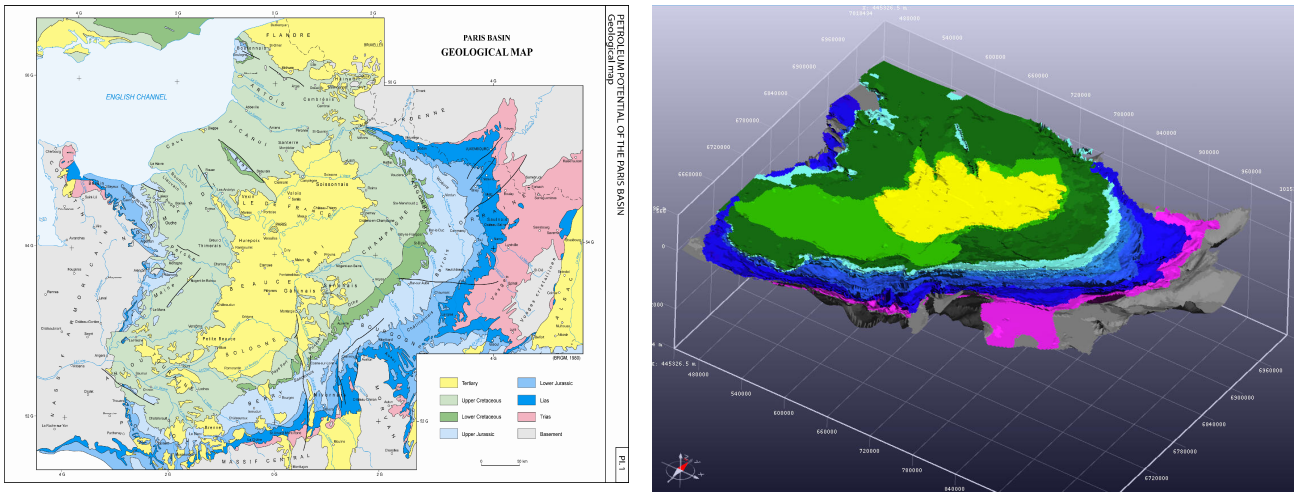

Figure 1: Geological map of the Paris basin (left) and 3D view of the stacked 11 main horizons used to construct the model (right).

In order to construct the basin model of the Paris basin, several types of data were gathered. The current surface topography and 11 horizons representing the top of a number of selected geological layers were constructed from outcrop boundaries, well and isobath maps. These 12 surfaces describe the general structure and geometry of the Paris Basin (Figure 1 - right).

Fourteen facies maps were available for the first stages (from the Anisian-Scythian to the Oxfordian stages). The composition of the upper layers was assumed to be spatially homogeneous with a single lithofacies defined for each layers. However these facies were defined as a mixture of different lithologies to account for the actual vertical variation within a layer.

Modelling approach

The first step of the basin modelling process is the "backstripping". Backstripping is a method to analyse the filling history of a sedimentary basin. It involves the progressive "peeling-off" or removal of each sediment layer considering isostatic sediment decompaction due to this unloading (Figure 2). The subsidence, deposition and erosion history can be estimated quantitatively in reverse. It provides, for each step in the past, reconstructed geometries to prepare the forward fully –coupled simulation of the basin history.
The second step of the basin modelling process is the "the forward" simulation. The 3D fluid flow simulator solves simultaneously up to the present day several equations: conservation of mass and momentum for solids and fluids, compaction, energy conservation, the generalized Darcy law for the three-phase flow and if necessary the maturation and generation of hydrocarbons.

Once the basin restoration process is simulated, pressure, temperature and salinity fields are available at present time for the entire Paris basin (Figure 3 – left). These data are used as initial condition for the traditional reservoir simulator (Coores^{TM}). The CO_2 injection is then simulated starting from an initial state that is not necessarily at hydrostatic equilibrium. In order to maintain the regional flow during the injection and post-injection time, the same type of boundary conditions is used in both the basin simulator and the reservoir simulator. The numerical simulation of the CO_2 injection and its induced pressure pulse (Figure 3 – right) is better constrained with the use of a more accurate initial hydrodynamic regime than with an usual hydrostatic state.

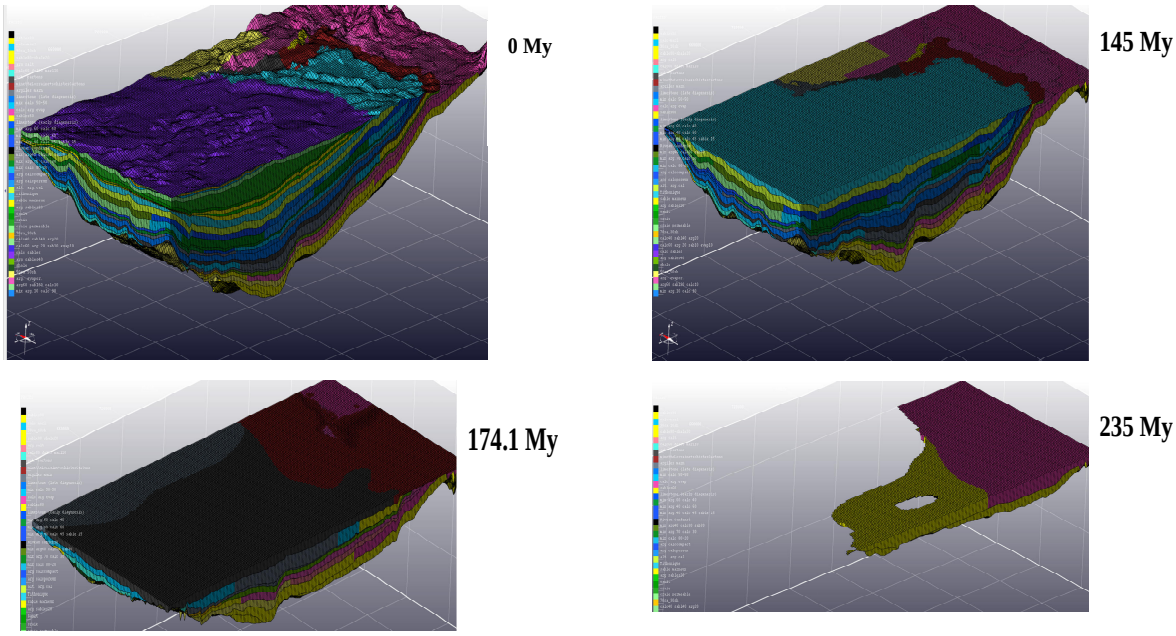

Figure 2: Four 3D views of the backstripped Paris basin model in TemisFlow™ software.

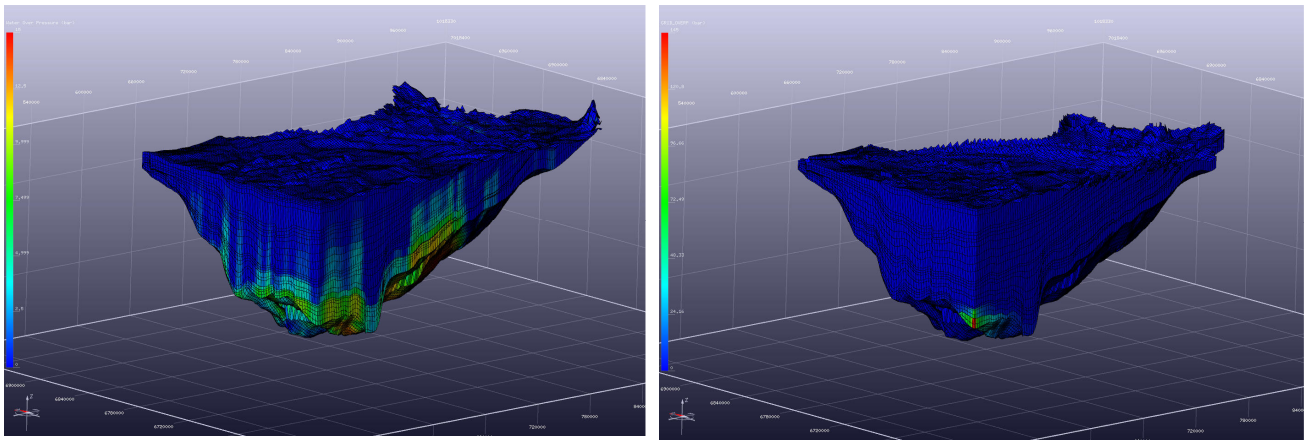

Figure 3: Overpressure (difference between simulated Pressure and hydrostatic Pressure) before CO_2 injection (left – 15 bar max) and after CO_2 injection (right– 145 bar max)

Conclusions

This study has shown that it is possible to couple:

- a basin simulator in order to compute the present-day pressure, temperature and salinity fields consistent with the basin geological history,
- a reservoir simulator which simulates the injection and long-term fate of the CO_2 in a reservoir with its initial condition derived from the basin simulator results.

Such a coupling allows to take into account the initial hydrodynamics and the pressure singularities of a reservoir and thus to have a better long term CO_2 storage prediction.