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A new approach for evaluating the impact of fluvial type heterogeneity in CO_2 storage reservoir modeling

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ABSTRACT

In this sensitivity analysis on a 3D model of a heterogeneous fluvial reservoir, two scenario orders have been considered. The first one focuses on the *first-order heterogeneity* (i.e. a fluvial belt with a 100% sand content), and the other one on the *second-order heterogeneity* accounting for the internal sedimentary fill within the fluvial belt (oxbow lakes). CO_2 injections were simulated using THOUGH2, and the dynamic simulations show large variations of reservoir performances. The first-order heterogeneity generates a large spectrum of storage capacities ranging from 30 to 50 Mt, to be related to the natural connectivity variability between fluvial belts induced by the avulsion process. Considering second-order heterogeneity reduces the storage capacities by 30%, highlighting the importance of representing such objects in complex heterogeneous systems. Moreover, it increases the dissolution process, increasing by the way the storage efficiency. The CO_2 plume extension and geometry is also estimated to be strongly dependent on the level of heterogeneity. Finally, trapping into poorly connected fluvial point bars affects strongly the storage capacity of the mobile CO_2 as well as the pressure field.

1. Introduction

Whatever its nature (sedimentary, fracture, diagenetic...) or the considered scale (from pore to basin), the heterogeneity of the rock is a major uncertainty in reservoir production and management, especially with the exploitation of complex reservoirs such as tight, fluvial or fractured reservoirs. While the oil industry has been working on the subject for decades with detailed studies (Journel et al., 1998; Larue and Friedmann, 2005; Larue and Hovadik, 2008; Pranter et al., 2007; Xiangyun et al., 2007), some other disciplines such as Carbon Capture Storage (CCS) only start to look after sedimentary heterogeneity and their impact on flow performances. Flett et al. (2007) have demonstrated the impact of varying quantities of sand and shale on the migration of CO_2 and the effectiveness of certain storage mechanisms. Pilot and commercial-scale sites like Ketzin in Germany and Snøhvit in the North Sea (Norway) have shown the difficulties encountered when predicting CO_2 injectivity and gas migration in highly heterogeneous reservoirs, such as fluvial-deltaic ones (Kempka et al., 2010; Wiese et al., 2010).

One may think to apply the geostatistics-based workflows used in petroleum reservoir characterization for assessing the risk on CO_2 injectivity and migration facing heterogeneities. However, geostatistical approaches are dedicated to reproduce 3D geological models that are conditioned to subsurface data. Since data sets are very

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limited in CCS, their use may be less relevant as uncertainties are huge. Moreover, these techniques hardly reproduce accurate heterogeneities. In this context (i.e. very few data), reservoir analogue models are used to fill the gap and to build the parameter sets required for applying geostatistical techniques. However, even in this case, difficulties still exist with the reproduction of continuous bodies and accurate connectivity from very sparse conditioning data.

Issautier et al. (2014) proposed a model-driven algorithm (SCSS) whose goal is to stochastically reproduce highly heterogeneous reservoir models stemming from outcrop data. In this approach, the stochastic simulations are conditioned on a stratigraphic conceptual model rather than data. The study was devoted to the analysis of the impact of the sedimentary heterogeneity on the reservoir performances, and it demonstrated:

- the impact of the heterogeneity on the reservoir performances at two different scales (first-order: connectivity of the reservoir bodies; and second-order: impact of the sedimentary fill);
- the impact of the geostatistical (SIS, SCSS) methods on the storage capacity.

In this paper, we propose to develop a similar protocol using dynamic simulations with as final objective to assess the impact of first- and second-order heterogeneities on storage capacities, overpressure, CO_2 dissolution, and migration.

For the sake of understanding, the conceptual model and the SCSS technique will be recalled in a first section. Then, the protocol used to model CO_2 injection will be presented. The results and their analysis will be then described and discussed.

2. Conceptual deposition models

In the SCSS algorithm, the geological rules and scenario are included in what is called the "conceptual geological model". In the present study, the concept is directly derived from the outcrop study carried out in central Saudi Arabia on the Minjur Sandstone combined to literature data, especially for object dimensions and stacking pattern (Gibling, 2006; Issautier et al., 2014; Jordan and Pryor, 1992; Miall, 2002). We chose to integrate an outcrop study to better constrain the connectivity parameter. Moreover, the Minjur Sandstone (Issautier et al., 2012a,b) is an analogue of the Triassic European reservoirs in terms of depositional environments, climate and geodynamic contexts, and this study might provide answers about the reservoir performances of such deep saline aquifers in CCS, geothermal and energy storage contexts.

The concept illustrates a depositional sequence and it involves three different sedimentary bodies:

- sheetlike sandstone (i.e. braided type deposits);
- multi-story meander belt;
- single-story meander belt.

To stochastically reproduce this conceptual model, an algorithm was specifically developed using python© interacting with gOcad functions. The code allowed generating two series of 3D numerical models that account for the conceptual geological model. Each pair of models from the two series shares the same architecture and only differs in their internal channel body infill (Fig. 1):

- first-order: the reservoir bodies, i.e. the fluvial belts consist of "homogeneous" stacked point bar sand bodies embedded in a shaly floodplain;
- second-order: the point bar bodies contain internal sedimentary heterogeneity (shaly oxbow lakes) which compartmentalizes the reservoir.

CO_2 injection modeling: the grid covers an area of 25 km × 25 km with a thickness of 60 m. With a resolution of 80 m × 80 m × 2 m, the grid contains 2,500,000 cells. A finer gridding would be suitable to ensure the heterogeneity integrity; yet, it would involve a much larger grid. Consequently, we assume this resolution to be the most adapted to flow simulations in this study. Two facies are considered with constant petrophysical values within each, so that porosity and permeability cannot "mask" the first- and second-heterogeneity signals on the reservoir performances (Table 1).

Flow simulations are performed with TOUGH2-MP (Zhang et al., 2008). The injection is set up in the center of the model, only in sand cells. Because the models are stochastic, none of them has the same amount of available "injection cells". Injections are simulated over 50 years and are pressure-controlled with a maximum injection pressure of 1.5 times the initial hydrostatic reservoir pressure to prevent a probable caprock failure. Consequently, the flow rates vary and evolve with time, depending on the

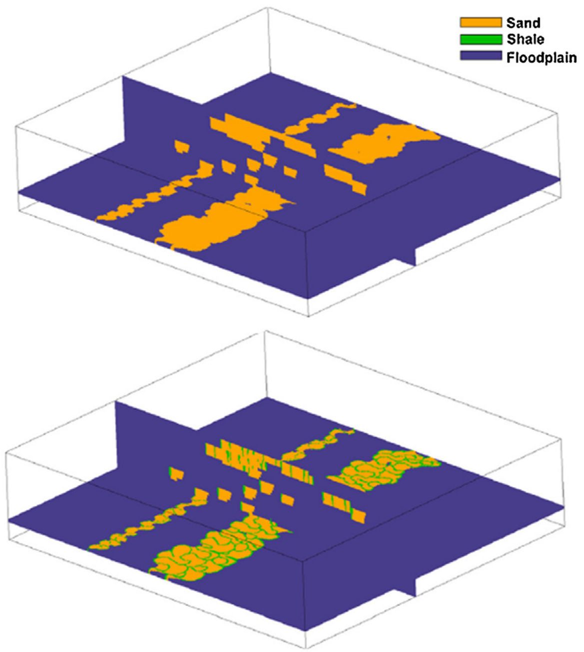

Fig. 1. (Color online.) Example of one scenario with two levels of heterogeneities: point bar only (up) and presence of oxbow lakes (right). Two bodies might be seen: the single-story meander belt on the left of the models and the multi-story meander belt on the center of the models.