2 Model Setup

Sedimentary basins are formed by superposition of high and low permeable strata that control the lateral and vertical flow of the fluids in the medium. Aquifers consist of layers with high permeability and therefore usually have pressure distributions that are (amost) hydrostatic. Lower-permeable parts of the basin are called aquitards, and here the flow will be orders of magnitude slower than in aquifers. However, the area exposed to flow may be very large, which consequently enables large volumes to flow across bedding between two adjacent aquifers. Aquifers and aquitards can be covered by evaporitic beds that are almost impermeable (aquicludes) [24].

The flow in aquifers generally depend on the balance between viscous, capillarity, and segregation forces. Viscous forces act because of the pressure change imposed by wells or background flow within the medium. In regions with slow velocities, capillary forces will dominate and in high permeability regions, gravity segregation can be considerably dominant. Any of these forces can be important for the movement of the injected CO_2. Herein, we consider the injection and early migration phase for a storage operation in which supercritical CO_2 is injected into a shallow-marine reservoir underneath a sealing cap-rock that forms a type of structural trap that is often seen in petroleum reservoirs. This means that we can expect viscous dominance during injection and gravity dominance during the subsequent migration phase.

To represent the aquifer geology, we use an ensemble of synthetic models developed in the SAIGUP study [38]. The SAIGUP models were originally designed to encompass the sedimentological architectures and fault structures of European clastic oil reservoirs, with a focus on shoreface reservoirs. Here, the deposition of sediments is due to variations in sea levels so that facies are forming belts in systematic patterns (curved belts for river deposits, parallel belts for wave deposits, etc). Sediments are deposited when the sea level is increasing, whereas barriers may be formed when the sea level is decreasing. Shoreface reservoirs are bounded by faults and geological horizons.

To derive an objective geological parametrization, the SAIGUP project indexed a broad suite of shallow-marine reservoir to continuously varying anisotropy and heterogeneity levels, structural complexity ranges from unfaulted to compartmentalized, and fault types from transmissive to sealing. From this, a set of geological realizations were created with sedimentary heterogeneity changing in different levels of heterogeneity in lateral and vertical directions. Structural heterogeneity was represented by variations of the fault orientations, intensity, and the transmissibility across the fault. Particular care was taken to ensure that the number of realizations was sufficient to form a basis for sensitivity analysis and that there was enough overlap in the geological parameter variations between realizations to allow for quantitative assessment of the contribution of each geological parameter. Although models are synthetic, each realization should be complex enough to represent a plausible geology suitable for realistic flow modeling.

The geological realizations were built within a sequence stratigraphic framework for progradational shallow-marine sedimentary environments. A regular grid was used to model the sedimentological parameters, with structural modeling added to the models afterwards. The depositional modeling started by population of six facies associations, each with internal heterogeneity on a fine grid. Lamina-scale models (meter-scale) were built to capture the lamina-scale effects on flow through each facies. Some of these facies were modeled in three dimensions to account for anisotropy; some were modeled deterministically, while other facies were populated stochastically. Figure 1 shows an illustration of the modeled facies for a specific case. Next, the facies produced at appropriate lamina scales were upscaled by geo-pseudo methods in different intermediate steps and finally mapped onto a geological grid. This grid was considered too fine for the flow simulation and was upscaled in a last step to a coarse grid (Figure 2). Each grid-block in the coarse simulation model were represented by values of porosity, net-to-gross ratio (shale content), directional permeabilities, and an index to the facies contained in the grid-block. Specifications of the fine and coarse grids are given in Table 1.

In our study, we have selected the following five parameters that altogether give 160 realizations:

Lobosity – is defined by the plan-view shape of the shoreline. As a varying parameter, lobosity indicates the level at which the shallow-marine system is dominated by each of the main depositional processes. Two depositional processes are considered in the SAIGUP study: fluvial and wave processes. The higher the amount of sediment supply provided from rivers is relative to the available accommodation space in the shallow sea, the more fluvial dominant the process