

Fig. 4. The river flows from left to right toward the sea on the model vertical section shown here (left figure). Aggradation angle is demonstrated in three levels (right figure); from top: low, medium and high aggradation angle. Between deposition and now, the entire system was rotated by tectonic effects such that the original river flow direction is oriented upward, not downward.

by huge levels of uncertainty. Many studies have shown the significance of geological heterogeneity on underground flow performance (e.g., Dutton et al., 2003; Eaton, 2006). To obtain a descriptive image of a feature, like faults and depositional structure, such that uncertainty can be reduced, we must provide adequate data. The process of data collection from underground layers is very costly, therefore it is important to know the ranking of influence each feature has on the flow in order to optimize the cost of data acquisition in modeling.

From the geological parameters that are relevant for shallow-marine deposits used in Ashraf et al. (2010a,b), we pick three parameters: the degree to which barriers may block horizontal and vertical flow, aggradation angle, and fault transmissibility. In addition to these, we consider the regional groundwater effect as an uncertain parameter in our study. Here, we give a brief description on each one, followed by the probabilities assigned to these parameters.

Barriers: During the formation of shallow-marine deposits, periodic floods result in a sheet of sandstone that dips, thins, and fines in a seaward direction. In the lower front, thin sheets of sandstone are inter-bedded with the mud-stones deposited from suspension. These mud-draped surfaces are potential significant barriers to both horizontal and vertical flow. In the SAIGUP realizations, these barriers were modeled by transmissibility multipliers in specific layers of the formation. The position of the barriers is generated by creating an elliptic cone-shaped surface that follows the plan-view shoreline shape of the facies, characterized from real world data (Howell et al., 2008). We define the degree of barrier presence by the areal percentage of zero-valued transmissibility multipliers. Fig. 5 shows a medium level of barriers.

Aggradation angle: in shallow-marine systems, two main factors control the shape of the transition zone between river and basin: the amount of deposition supplied by the river and the accommodation space that the sea provides for these depositional masses. Deposition happens in a spectrum from larger grains

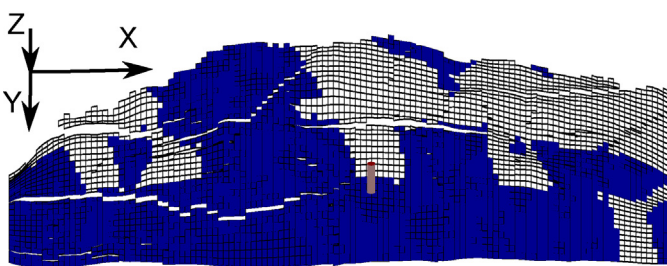


Fig. 5. The figure shows 50% of zero transmissibility multipliers in a specific model layer representing a medium level of barriers. One layer of the model is shown in the figure.

depositing earlier on the land side, to fine deposits happening in the deep basin. If the river flux or sea level fluctuates, equilibrium changes into a new bedding shape based on the balance of these factors. In the SAIGUP study, progradational cases are considered, in which river flux increases and shifts the whole depositional system into the sea. The angle at which transitional deposits are stacked on each other because of this shifting is called the aggradation angle. Three levels of aggradation are shown in Fig. 4: low, medium and high. The study reported in Ashraf et al. (2010a,b) showed that aggradation can have a dramatic influence on the injection and migration process.

Fault transmissibility: Huge uncertainties can be involved when modeling the presence of faults. Faults are discrete objects that are modeled by changing the geometry of the simulation grid. The transmissibility for flow across faults changes during the process of faulting. This causes a spectrum of transmissibilities, from a sealing fault with no flow across it, to a fault that has not produced any barriers to the flow within its opening space.

Within a simulation grid, the influence of faults on the local and global flow behavior depends on a number of parameters including fault length, orientation, intensity and transmissibility. The well location with respect to the faults can change the overall behavior of injected CO₂ plume significantly. In the SAIGUP models, different levels of fault orientations, transmissibility, areal intensity, and well patterns are considered. For this study, we consider all fault modeling parameters at their medium level and consider to vary only the fault transmissibility. These variations, however, do not affect the definition of the no-flow boundary, which is motivated by the presence of an impermeable fault.

The used geology realizations contain compartmentalized fault systems comprising approximately equal densities of strike-parallel and strike-perpendicular faults based on a portion of the Gullfaks field (Manzocchi et al., 2008; Howell et al., 2008). Fig. 6 shows the fault pattern and location of the injector considered for the study.

It is shown in Manzocchi et al. (1999) that the transmissibility multiplier provides a numerically more robust representation of faults within reservoir simulation than conventional permeability multipliers. We consider the fault transmissibility multipliers to range between zero and one. A multiplier value of one corresponds to a fault permeability equal to the harmonic average of cell permeabilities across the fault, i.e., to a fault without any influence on flow (Manzocchi et al., 1999).

Regional groundwater effect: geological modeling always comes with the uncertainty of how large the aquifer is and how it is connected to other underground aquifers. This is a direct consequence of the need to define boundary conditions to limit the computational domain, which cannot always coincide with meaningful physical boundaries in large-scale systems. However,