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Inverse modeling of geochemical and mechanical compaction in sedimentary basins

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We study key phenomena driving the feedback between sediment compaction processes and fluid flow in stratified sedimentary basins formed through lithification of sand and clay sediments after deposition. Processes we consider are mechanic compaction of the host rock and the geochemical compaction due to quartz cementation in sandstones.
Key objectives of our study include (i) the quantification of the influence of the uncertainty of the model input parameters on the model output and (ii) the application of an inverse modeling technique to field scale data. Proper accounting of the feedback between sediment compaction processes and fluid flow in the subsurface is key to quantify a wide set of environmentally and industrially relevant phenomena. These include, e.g., compaction-driven brine and/or saltwater flow at deep locations and its influence on (a) tracer concentrations observed in shallow sediments, (b) build up of fluid overpressure, (c) hydrocarbon generation and migration, (d) subsidence due to groundwater and/or hydrocarbons withdrawal, and (e) formation of ore deposits. Main processes driving the diagenesis of sediments after deposition are mechanical compaction due to overburden and precipitation/dissolution associated with reactive transport.
The natural evolution of sedimentary basins is characterized by geological time scales, thus preventing direct and exhaustive measurement of the system dynamical changes. The outputs of compaction models are plagued by uncertainty because of the incomplete knowledge of the models and parameters governing diagenesis. Development of robust methodologies for inverse modeling and parameter estimation under uncertainty is therefore crucial to the quantification of natural compaction phenomena.
We employ a numerical methodology based on three building blocks: (i) space-time discretization of the compaction process; (ii) representation of target output variables through a Polynomial Chaos Expansion (PCE); and (iii) model inversion (parameter estimation) within a maximum likelihood framework. In this context, the PCE-based surrogate model enables one to (i) minimize the computational cost associated with the (forward and inverse) modeling procedures leading to uncertainty quantification and parameter estimation, and (ii) compute the full set of Sobol indices quantifying the contribution of each uncertain parameter to the variability of target state variables.
Results are illustrated through the simulation of one-dimensional test cases. The analyses focuses on the calibration of model parameters through literature field cases. The quality of parameter estimates is then analyzed as a function of number, type and location of data.