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Uncertainty analysis of basin scale compaction processes

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The dynamic evolution of porosity distribution in sedimentary basins has been typically interpreted by assuming that mechanical compaction is the dominant process. While mechanical compaction is particularly relevant during the early burial phase and has been often assumed to play a key role in the diagenesis even at the largest depths, temperature-activated geochemical compaction has been recognized as a major component driving the evolution of the basin characteristics and of the compaction process at least within the deepest layers. As a consequence, modeling basin evolution requires solving a coupled system involving partial differential equations and algebraic relationships between state variables. In this framework, quartz cementation and smectite-illite transformation are recognized to be the most relevant processes affecting sedimentary basins evolution. Spatial and temporal scales of basin evolution are intrinsically very large and it is often difficult to provide reliable estimates for the parameters included in the selected geochemical and compaction models.

In this study we focus on the effects that the coupling between the quartz cementation process and mechanical compaction have on the distribution of porosity, pressure and temperature in the evolving sedimentary basin in the presence of uncertain model parameters and boundary conditions. We quantify uncertainty associated with the system state variables by means of a Global Sensitivity Analysis (GSA). The methodology is framed within the context of a generalized Polynomial Chaos Expansion (GPCE) approximation of a basin-scale evolution scenario. Sparse grids sampling techniques are employed to improve the computational efficiency of the methodology. The theoretical and computational framework adopted allows an efficient computation of the variance-based Sobol indices, exploiting a polynomial interpolation over the sparse grid collocation points. An additional advantage of the GPCE is that it yields a surrogate model of the system behavior. This can be exploited within the context of uncertainty propagation studies, e.g., based on numerical Monte Carlo simulations. It allows observing the space-time evolution of the probability density distribution (and its statistical moments) of target problem variables. The approach is illustrated through a one-dimensional example involving the process of quartz cementation in sandstones and the resulting effects on the dynamics of porosity, temperature and pressure.