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A new approach combining geological characterization and reactive transport for a quantitative integration of diagenesis in stratigraphic forward models

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Advanced carbonate reservoir characterization and modeling consists in the quantitative integration of the diagenetic overprint into the sedimentary model and its association with petrophysical properties. A new challenge for carbonate reservoir characterization is thus to model diagenesis and the derived reservoir heterogeneities. A large number of works has already been published on this topic, following different approaches (e.g. forward, stochastic, and/or geochemical modeling). This paper proposes an integrated approach, based on geological characterization and reactive transport modeling, a powerful tool to evaluate mineralogical and petrophysical transformations induced by fluid-rock interactions in geological processes.
The case study corresponds to the well-exposed Late Oligocene-Early Miocene succession of southeastern France, that allows pertinent investigation of the early diagenesis in meteoric and brackish environments. This area provides unique and continuous outcrops of a mixed sedimentary succession (carbonate-siliciclastic shallow facies) with five particular sedimentary discontinuities resulting from various processes such as subaerial exposure, submarine erosion or bioturbation.
Stratigraphic forward simulations were achieved on this study area, in order to attest for the stratigraphic architecture and facies distribution observed in the field. Modeling allowed to constrain the spatial and temporal distribution of depositional facies and specific parameters related to diagenetic environments (e.g. mineralogy of host-rock, residence time of seawater/freshwater). Reactive transport simulations have been performed by coupling a geochemical calculation code and a multicomponent, multiphase, non-isothermal reservoir simulator. The thermodynamic database used for this study is SLOP98, and the activity model for aqueous species is the B-dot equation. Kinetic parameters for mineral dissolution come from the 2004 USGS compilation. Precipitation kinetics have been adjusted to obtain an aragonite half-life of about 5000 years. The considered mesh is a 25km-by-16m vertical 2D-section extracted from the stratigraphic forward simulation. Each cell is 500m-long in X-direction and from 0.15 to 3.5m in Z-direction to reproduce the site topography. Based on the sedimentology study, seven facies were defined in this model, containing different contents of quartz, calcite cement, calcite grains, and aragonite grains. The model is initially fully saturated with seawater. Groundwater recharge is modeled by a constant flow rate imposed on the top layer of the model. This flow rate corresponds to a 1200 mm mean annual precipitation, and the injected fluid composition is rainwater equilibrated with a 10-2 bar partial pressure of CO_2. Bottom and side boundaries are set to hydrostatic pressure. Total simulation duration is about 30,000 years.
This integrated approach, combining stratigraphic forward modeling and reactive transport simulations, allowed a quantitative evaluation of early diagenetic processes on reservoir properties. This feasible workflow can be applied to other problematic related to carbonate diagenesis.