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Revealing the Hidden Dynamics of Clay-Coated Quartz Grains in Sandstone with Multiphase-Field Modeling

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The quality of the sandstone reservoir is critically influenced by the presence of clay coatings on the surfaces of quartz grains. These coatings play an essential role in determining porosity and permeability, key parameters that govern the storage and flow potential of sandstone reservoirs used for geothermal energy, groundwater, and hydrocarbons. This study employs a multiphase-field model, a versatile tool widely used in materials science, to simulate the complex interplay of interface motion and phase transitions within geological systems. By generating a detailed three-dimensional digital representation of sandstone, the model provides precise control over quartz grain coatings and composition, enabling a thorough investigation of their impact on reservoir properties. Two central aspects are explored: (1) the effect of varying clay coating coverage on quartz grains, and (2) the influence of coating distribution on the evolution of porosity and permeability during quartz precipitation. Computational fluid dynamics (CFD) simulations further quantify the changes in permeability at different stages of grain growth, revealing intricate relationships between the distribution of the coating, the properties of the rock, and the dynamics of fluid transport. The findings show that sandstones with a higher proportion of coated grains exhibit enhanced permeability due to the cement growth limiting effects of clay coatings on quartz grains. These insights provide a deeper understanding of the mechanisms that govern sandstone reservoir quality and offer practical implications for optimizing applications in geothermal energy, water resource management, and carbon and hydrogen storage.