New approaches to predict top seal integrity of geological reservoirs: Case study examples from the Vienna Basin

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Seal rock integrity is not only an important success factor in hydrocarbon exploration but also highly relevant in a geological storage context. Top seal leakage may play a significant role in the preservation of accumulated fluids (e.g., primary oil and gas or injected storage fluids), but also the potential interaction of pore fluids with the seal rock (e.g., induced diagenesis by storage gases such as H_2 or CO_2). This work presents recent developments in the prediction of seal capacity and the detection of top seal leakage in the Miocene (Badenian to Pannonian) Vienna Basin infill. Different state-of-the-art characterization techniques such as micro-computed tomography, broad ion beam-scanning electron microscopy, gas physisorption with N_2, CO_2 and Ar, as well as nuclear magnetic resonance spectroscopy combined with core plug saturation experiments are introduced and their capabilities to visualize multi-scale changes in seal rock properties are discussed. Fluid Inclusion Chemostratigraphy was used for the first time as a geochemical tool for the detection of migration and/or diffusion through low-permeable top seals, and these results are critically reviewed based on complementary petrophysical and petrographical data as well as existing core descriptions and wireline log interpretations. Furthermore, a workflow for seal capacity prediction based on established normal compaction trends and resulting models for porosity, displacement pore throat radius and permeability is introduced and the major controlling factors for the estimated breakthrough pressures and corresponding maximum hydrocarbon column heights (e.g., facies and mineralogical changes, burial compaction) are outlined. Particularly, Badenian mudstone pore space characteristics show a considerable facies sensitivity closely linked to the respective well position related to paleo-delta or shoreline regions. These changes are illustrated based on results from advanced scanning electron microscopy-based petrography and image processing. Finally, first petrographic and geochemical evidence for a direct relationship between vertical hydrocarbon migration through top seals and induced diagenesis within these low-permeable layers (mainly calcite cementation) is provided. Based on the presented case study results, top seal leakage and vertical migration through semi-permeable mudstone layers have to be considered important fluid transport mechanisms besides the arguably dominant fault-controlled vertical migration.