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Modelling and Simulation of Gas Migration through the Gas Hydrate Stability Zone in Marine Geosystems

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Methane hydrates constitute a dominant organic carbon pool in the earth system and an important intermediate ”capacitor” in the global methane budget. Gas hydrates are predominantly formed from biogenic methane that is generated by methanogenesis in the deep biosphere. This methane migrates upwards as free gas or methane-rich porewater by advection. This fluid flow is caused by non-steady state sediment compaction (passive margins), compaction of oceanic sediments during subduction (active margins), and dewatering of minerals at elevated temperatures (passive+active margins). Over geological times, the hydrates accumulate close to the bottom simulation reflector (BSR, lower stability limit of gas hydrates) because, the methane flux from below leads to hydrate formation in the gas hydrate stability zone (GHSZ), but the ongoing sedimentation tends to bury the hydrates below the GHSZ where the hydrates dissociate, and the released methane gas migrates back into the GHSZ to re-form the hydrates. Towards the seafloor, the hydrates dissolve due to undersaturation of porewaters as a consequence of anaerobic methane oxidation (AOM). Some methane gas by-passes the GHSZ and AOM zone if the upward flow is larger than the reaction rates. This methane fuels rich cold seep ecosystems. In order to understand this role of gas migration through the GHSZ in the natural carbon cycle, we have developed a multiphysics mathematical model and numerical solution framework for methane hydrate geosystems occuring in marine settings. The model considers coupled nonisothermal multiphase multicomponent reactive transport processes on geological time (hundreds of thousand years) and spatial (tens of kilometer) scales. The model incorporates complex fluid phase transitions in a variationally consistent manner within a single Newton iteration loop, and is therefore, very robust. In this talk, we will present an application of our model to analyze the sedimentation driven migration of methane gas through the GHSZ in one of the most dynamic natural setting of the Black Sea paleo-Danube gas hydrate system. We will discuss the specific numerical challenges of this problem setting, and show the robustness of our numerical strategy in terms of handling these numerical challenges.