

Fracture-driven methane bubble ascent within shallow fine-grained clay-bearing aquatic sediments: dynamics and controlling factors

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Mature methane gas bubbles in the fine-grained, clay-bearing (cohesive) aquatic sediments, found at many locations throughout the world, are much larger than the characteristic pore size. When gas pressure within the bubble is high enough to overcome compression, friction, and cohesion at grain contacts, gas migrates upward driven by buoyancy, by pushing the grains apart and fracturing the fine-grained sediments. Fracturing of the fine-grained cohesive sediments by the migrating bubbles destabilizes sediment and might result in slope failure. Migrating methane bubbles may bypass processes of oxidation in the upper sediment layers due to their fast rise velocity, release to the water column and eventually to the atmosphere. In this study we use coupled macroscopic single-bubble mechanical/reaction-transport numerical model to explore bubble ascent under various ambient concentration profiles, associated with bio-chemical processes of methane production and consumption below sediment-water interface, as it occurs in nature. Modeling results show that changes in the ambient dissolved-methane concentrations strongly affect bubble ascent velocity. It is demonstrated that bubble migration scenario within fine-grained muddy sediments is controlled dominantly by the internal bubble pressure that manages solute exchange with adjacent porewater. It is significantly affected by the total hydrostatic pressure. For shallow water depths two sequential bubble propagation patterns were observed: (1) Stable (saw-tooth) fracturing, followed by (2) Dynamic (unstable, rising line) fracturing, leading to an ultimate release of the bubble to the water column. However, for a higher water depth, bubble propagation pattern is characterized by stable fracturing only. In this pattern the bubble becomes more sensitive to the ambient field of methane concentrations and may stop below sediment-water interface due solute release caused by the local methanotrophy.