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Joint inversion of controlled-source electromagnetic and full waveform seismic data for gas hydrate assessment

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We present a petrophysically coupled joint inversion of controlled-source electromagnetic (CSEM) and seismic data for marine gas hydrate assessment. We begin by building a simple one dimensional geological model consisting of a sedimentary host containing a layer of hydrate above a layer of free gas. From the sediment porosity, the hydrate saturation and the gas saturation we use well established petrophysical relationships such as Archie's Law, Wyllie's equation and Gassman's equation to create corresponding geophysical models of resistivity, density, P-wave velocity and S-wave velocity. We then calculate synthetic marine CSEM data, reflection traveltime data, amplitude versus offset (AVO), synthetic traces, and the elastic full waveform response for these models. Focusing on combining CSEM data with full waveform seismic data, we perform a linearized joint inversion for the hydrate and free gas saturation, coupling the models at the petrophysical level. In both the hydrate and the free gas layer, sediment resistivity is governed by Archie's law; resistivity increases when either hydrate or free gas is present since both of these components displace conductive seawater in the pore space. However, elastic rock properties differ between hydrate and gas filled sediments. In the hydrate zone, the P-wave velocity is controlled by the Wyllie relation and is typically higher than the surrounding sediment, while the velocity of the gas layer is controlled by Gassman's equations and is typically lower. It is necessary to incorporate these different elastic rock models into a petrophysically coupled joint inversion. We use the BSR, identified on conventional reflection seismic sections as the phase boundary between hydrate and free gas, to divide the model into two regions prior to the inversion. Above the BSR, Wyllie's relation is used, while below the BSR, Gassman's equation holds instead. Results show that such a joint inversion of CSEM and full waveform seismic data produces better estimates of hydrate and free gas saturation than the use of each individual method alone.