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Remote determination of the gas hydrate content of marine sediments using effective medium theory

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Methane present in the upper few hundred metres below the seafloor in water depths greater than a few hundred metres on continental margins is stored primarily in the form of clathrate hydrate. Large-scale estimates of methane volumes and fluxes in continental margin sediments therefore must rely heavily on remote geophysical determination of hydrate content. Since hydrate has significantly higher elastic moduli than pore water, the presence of hydrate causes an increase in the P wave velocities, particularly if it acts to cement together sediment grains. The effect on S wave velocities is more complex and less well understood. Effective medium models relate the physical properties of a composite medium such as hydrate-bearing marine sediments to those of the individual constituents. A variety of such models have been developed to predict the elastic properties of such sediments. Commonly one or more unmeasurable parameters are adjusted to make such models fit laboratory datasets. We have developed an effective medium approach to hydrate quantification in clay-rich, hydrate-bearing marine sediments based on the self-consistent approximation and the differential effective medium theory. The presence of hydrate also results in increased P and S wave attenuation, an observation that is surprising in view of the fact that hydrate is expected to restrict the flow of pore fluid, and attenuation at seismic frequencies is expected to occur primarily due to viscous losses in the pore fluid. We explain this increase using Biot and squirt through a hydrate microstructure that is formed within the sediment microstructure. Our effective medium model is formulated in an inversion algorithm that predicts hydrate content and its uncertainties from measurements of P and S wave velocities and attenuations or a subset of these parameters. We present some examples of the application of this algorithm.