Theoretical modelling insights into elastic wave attenuation mechanisms in marine sediments with pore-filling hydrate

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Introduction

Methane stored in seafloor hydrate is a relatively clean fossil fuel resource that has the potential to ease the transition to renewable energy in future. Methane stored in hydrate-bearing sands presently forms the most commercially attractive hydrate reservoirs [Boswell and Collett, 2011], whether on the seafloor or in terrestrial permafrost regions. In coarse grain deposits, hydrates are prone to exhibit a pore-filling habit for hydrate saturations below ca. 40%. This type of hydrate-bearing sediments does not show significant changes in P- and S-wave velocities [Waite et al., 2009] with respect to the background sediment (in contrast with sediments hosting coat and/or grain contact cementing hydrate) because the hydrate is suspended within the water and hence only increases the bulk modulus of the effective pore fluid. P- and S-wave attenuation may be used as an alternative indirect geophysical parameter to estimate hydrate saturation [Best et al., 2013] and it is indeed an attractive alternative especially in pore-filling hydrate-bearing reservoirs where traditional P- and S-wave velocity methods are not effective.

Methods. The Hydrate-Bearing Effective Sediment Model

Here we present the Hydrate-Bearing Effective Sediment (HBES) rock physics model to calculate frequency dependent P- and S-wave velocity and attenuation of an effective porous medium composed of solid mineral grains, methane hydrate, methane gas, and water. The HBES model considers elastic wave energy losses caused by: local viscous flow both i) between fluid inclusions in hydrate and pores (sub-micro squirt flow), and ii) between different aspect ratio pores created when hydrate grows (micro squirt flow); the relative motion of the frame with respect to the pore fluid (Biot's type fluid flow); and gas bubble damping.

Results

The sole presence of pore-filling hydrate affects both the porosity and intrinsic permeability of the sediment, and hence the attenuation caused by the relative motion of the grains with respect to the fluid in the pores at high frequencies above 10^4 Hz. The model predicts frequency related changes in velocity at frequencies where attenuation changes also occur (Figure) as stated by the Kramers-Kronig relations. Attenuation maxima due to sub-micro squirt flow generated by fluid inclusions in hydrate occur over the whole frequency range, depending on both the aspect ratio and type of fluid of the inclusions, whereas peaks due to micro squirt flow generated by different aspect ratio pores occur at sonic to ultrasound frequencies, independent of the aspect ratio of pores.

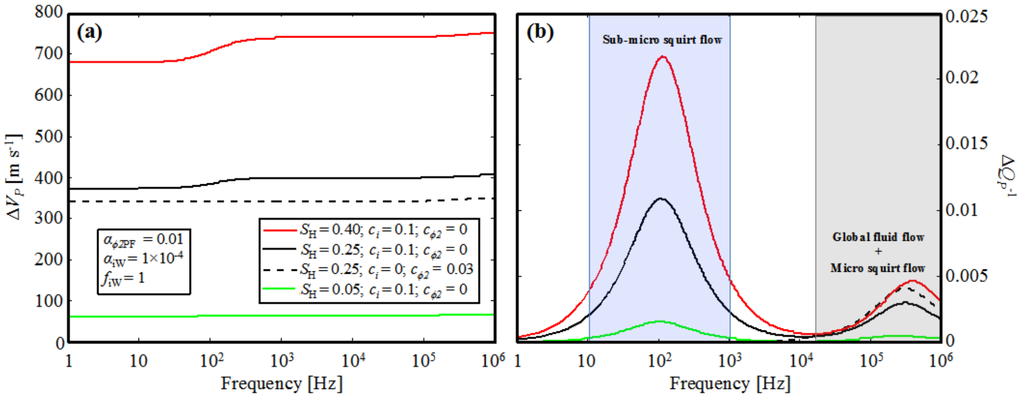

Figure: Variation in P-wave (a) velocity and (b) attenuation with frequency in sediment with pore-filling hydrate relative to the values without hydrate.

Discussion and Conclusions

Traditionally, attenuation models have treated wave velocity and attenuation independently [Lee et al., 2006] which potentially contravenes the Kramers-Kronig relations of causality. Our proposed HBES model is causal and shows that attenuation maxima due to fluid inclusions in hydrate are possible over the entire frequency range of interest to exploration seismology (1-10^6 Hz), depending on the aspect ratio and type of fluid inclusions, whereas maxima due to different aspect ratio pores occur only at sonic to ultrasound frequencies (10^4-10^6 Hz). This frequency response imposes further constraints on possible hydrate saturations able to reproduce broadband elastic measurements of velocity and attenuation. Our results provide a physical basis for detecting the presence and amount of pore-filling hydrate in seafloor sediments using conventional seismic surveys.

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References

Boswell, R., and T. S. Collett (2011), Current perspectives on gas hydrate resources, Energy & environmental science, 4(4), 1206-1215, doi:10.1039/C0EE00203H.

Best, A. I., J. A. Priest, C. R. I. Clayton, and E. V. L. Rees (2013), The effect of methane hydrate morphology and water saturation on seismic wave attenuation in sand under shallow sub-seafloor conditions, Earth and Planetary Science Letters, 368, 78-87, doi:10.1016/j.epsl.2013.02.033

Lee, M. W. (2006), Is amplitude loss of sonic waveforms due to intrinsic attenuation or source coupling to the medium?, Sci. Invest. Rep. 2006-5120, 13 pp., U.S. Geol. Surv., Reston, Va.

Waite, W. F., et al. (2009), Physical properties of hydrate-bearing sediments, Reviews of Geophysics, 47(4), n/a-n/a, doi:10.1029/2008RG000279